INFLUENCE OF PLANT DENSITY AND INTERCROPPING ON MAIZE AND SOYBEAN GROWTH, LIGHT INTERCEPTION, YIELD, AND EFFICIENCY INDICES

BY

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Dedicated to the the memory of my father (T.A.) and my sister (Z.O.) for their strong, honest and lovely cares in my early days of life, my late friends (NGA. TH.) and (NK. L.M.) who stimulated and inspired my education.

To my mother, Djogue Ida, who put me in school, and who, with firmness mixed with love, incorporated into me the power of determination and dedication to do anything honest and constructive. I know she sacrificed everything for my education and success.

To my wife, Tetio Foudjio Regine, our daughter, Tetio Nanuoug E. Berthe, our two sons, Tetio P. Pascal and Tetio Djiogue S. Arnaud, for her unlimited patience and moral support.

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Major Department: Agronomy

Intercropping of maize with grain legumes is a stable cropping practice for most farmers in the tropics. For the practice to be successful, more information is needed on component plant density, canopy development and light flux. Field experiments were conducted in Gainesville, Florida (29° 38'N), during 1985 and 1986 to assess the effects of a wide range of maize (0.8 to 15.3 plants m^{-2}) and soybean (1.76 to 77.5) plant densities on growth aspects of maize and soybean and to evaluate the constant and time-weighted average plant densities (CPD and TWAPD) concepts for determining optimum densities of the intercrop components. Six intercrop soybean densities (1.8 to 24.0 plants m^{-2}) were planted, one in each of six maize systematic "fan" design across 15 maize densities. Cobb (MG VIII) and Davis (MG VI) soybean cultivars, and maize hybrid (Pioneer Brand '3192') were used. Three sole maize densities and the 24.0 plants m^{-2} intercrop soybean were growth analyzed biweekly. Percent light interception (PLI), leaf area distribution, leaf area index (LAI), dry matter (DM)

accumulation, crop growth rate (CGR), plant height, tiller number per plant, yield components, and assimilate distribution were recorded. Then, land equivalent ratio (LER) and area-time equivalent ratio (ATER) were calculated to compare CPD and TWAPD concepts.

Light interception in maize canopy was greatly concentrated at ear level. Light interception by tassel and flag leaf increased (2 to 40%) as plant density increased. The critical LAI was not reached by the 1.9 maize plant density. Plant height, DM accumulation, CGR, tillering, ear number per plant (ENP), kernel-row number per ear (KRNE), kernel number per-row (KNR), -ear (KNE), -plant and -unit area were significantly influenced by plant density. Weight per kernel (WK) per ear was not affected by plant density for ear 1. Yield components (KRNE, KNR, KNE, WK) differed among ears with ear 1 > ear 2 > ear 3, and were vulnerable to plant density as follows: ENP > KNE > KNR > KRNE > WK. With increasing plant density, maize and soybean yield per plant decreased in a reciprocal relationship, seed yield per unit area increased parabolically and vegetative dry matter increased asymptotically. Maize yield was not affected by the intercrop soybean. Intercrop soybean yield decreased reciprocally as maize density increased. Leaf area index, DM accumulation, and CGR of the two soybean cultivars were significantly reduced by both intercropping and increasing maize density. Land equivalent ratio and ATER for TWAPD were generally greater than for CPD. It is concluded that there is a "critical maize density" (CDm/s25) which suppressed intercrop soybean yield by at least 75% and differed with soybean cultivars and density. Constant plant density (CPD) concept underestimates the intercrop density combination and the productivity of the intercropping, compared to TWAPD.

CHAPTER I
INTRODUCTION

Maize (*Zea mays* L.) is one of the most important cereal crops in Cameroon. Generally it is grown with a legume such as common bean (*Phaseolus vulgaris* L.), cowpea [*Vigna unguiculata* (L.) Walp.], groundnut (*Arachis hypogaea* L.), and many other crops during a part or the whole of its life cycle. A mixture of up to 10 species at different plant densities and in close association is common. Recently, soybean [*Glycine max* (L.) Merr.] was introduced to farmers holding small and dispersed pieces of land, who produce about 80% of food crops in Cameroon. Mixed intercropping predominates as the cropping system, presumably better utilizing both space and time in meeting the human population food demands.

Intercropping is a stable and useful cropping practice for farmers with small and fragmented land holdings and limited production inputs (irrigation, pesticides, chemical fertilizers, machinery, and improved varieties). Intercropping is widespread in the tropical regions of the world, but it is used also in the temperate regions, especially with soybean production. In the semi-arid tropics intercropping can increase yields and economic returns over solecropping (ICRISAT, 1977, 1978). It is generally believed to be better adapted to the topographic, ecological, economic, and social conditions of the average family farm, thus allowing the farmers to live in equilibrium with their environment.

Interest in these complex intercropping systems in the research and extension education communities, because of the desire to learn more about the systems in order to provide better scientific and technological information and services has surged (Francis, 1985). Ecologists have been particularly attracted to the phenomenon of intercropping because of the biological diversity and the potential for improved productivity and sustainability.

Many aspects of intercropping have been studied. These included criteria for assessing yield advantages (Willey, 1979a), competitive relationships (de Wit, 1960; Donald, 1963; McGilchrist, 1965; de Wit and van den Bergh, 1965), biological efficiency (Osiru and Willey, 1972; IRRI, 1974, 1975), agronomic relationships (Trenbath, 1974; Wahua, 1978; Willey, 1979b), suitability of intercrop species (Francis et al., 1976; Tetio-Kagho, 1980; Davis and Garcia, 1983). However, plant density optima of intercrop components and methods of their determination for greater yields and biological efficiency need more resolution. Land equivalency ratio (LER), although widely used, is an inappropriate index of biological efficiency for food intercrop comparisons because the cropping system duration is not included in its calculation (Hiebsch and McCollum, 1987). They proposed area-time equivalency ratio (ATER) as a better index of biological efficiency, which accounts for differences in duration of the two cropping systems (sole and intercropping) compared. In addition, few LER calculations have used sole crops data from the necessary range of densities (IRRI, 1974).

In most maize/legume intercropping situations, maize is reported to be the aggressor component (Willey and Osiru, 1972; Hart, 1975; Crookston and Hill, 1979). If successful production of a companion legume such as soybean is to be achieved, more information on maize growth, development, and canopy structure in relation to plant density is needed.

This study was therefore conducted:

1) to assess the effects of a wide range of maize and soybean plant densities on the following:

a) canopy development, light interception, vegetative and reproductive growth, kernel and total dry matter yield of the maize intercrop component, and

b) vegetative growth, seed and total dry matter yield of the soybean intercrop component; and

2) to evaluate the method of determining optimum densities of intercrop components as a function of sole crop density by use of different efficiency indices.

CHAPTER II
MAIZE RESPONSES TO PLANT DENSITY: INFLUENCE ON LIGHT INTERCEPTION AND VEGETATIVE GROWTH

Introduction

Light is of primary importance for plant growth and development and crop yield. Dry matter production, assuming water and nutrient availability, is related directly to the exploitation of solar radiation (Donald, 1963; Williams et al., 1968; Daughty et al., 1983). Rate of soybean dry matter production is a function of percent solar radiation (cumulative) intercepted regardless of planting patterns (Shibles and Weber, 1966). However, the exploitation of solar radiation might depend on the canopy structure and associated leaf distribution.

Williams et al. (1968) observed that the effect of canopy architecture on the vertical distribution of light within the canopy can be a major determinant of photosynthetic efficiency and growth. In crop canopies, radiation is transmitted through and between leaves, and as a result radiation flux density and spectral composition change rapidly with depth (Szeicz, 1974; Gardner et al., 1985). The relationship between light interception and maize growth is fairly direct. Light interception increased with increasing leaf area index (LAI) and increased photosynthesis up to a "critical LAI" value (Pearce et al., 1965). Williams et al. (1968) found that an increase in LAI resulted in a proportional increase in light interception up to LAI = 3, and with further increase in LAI the function was asymptotic

up to 99% interception. They also observed that the peak light penetration values were associated with the peak crop growth rates. Early et al. (1966) reported a height increase in maize as light decreased from 100 to 40%, a leveling off at 30 and 20%, and a decrease at 10% to approximately that of full sunlight plants.

Increasing LAI by increasing plant density also increases the occurrence of less-active-photosynthetic structures, especially tassels, which may reduce the amount of solar radiation available to plants for photosynthesis. Simulated tassel-light interception ranged from approximately 4 to 20% over a range of 17,500 to 125,000 plants ha^{-1} according to a model developed by Duncan et al. (1967), i.e., tassel-light interception increased as the number of tassels increased. A particularly striking feature of the light attenuation patterns is the relatively low illumination at solar noon within 50 cm from the top of the crop at 50,000 and 125,000 plants ha^{-1} (Loomis et al., 1968). Loomis et al. concluded that the structure of the upper canopy is a critical determinant of light penetration and canopy illumination.

Generally, plant density and light interception and growth relationships have not been extensively studied in maize, especially over a wide range of densities. This information is needed, especially since maize is one of the most extensively used intercrops in most parts of the world. This study was therefore designed to assess the relationships of canopy structure, light interception, and vegetative growth of maize, ranging from low to ultra-high plant densities.

Materials and Methods

Field experiments were conducted on the Agronomy Farm at the University of Florida, Gainesville, during the 1985 and 1986 growing seasons. The soil, a Lake fine sand (hyperthermic, coated Typic Quartzipsamments), had a Melich I extractable test of 105 ppm P, 60 ppm K, 28 ppm Mg, 300 ppm Ca, and a pH of 6.1.

Design

Maize hybrid, Pioneer Brand '3192', was planted in a systematic spacing design ("fan") (Nelder, 1962) at 20 densities ranging from 0.52 to 28.9 plants m^{-2} in a nearly square arrangement. There was a 23.5% increment between densities. The "fan" (Fig. 1) contained 29 radii and 20 arcs. The dimensions were calculated using Bleasdale (1967b) basic equations for design,

$$(2\ N{-}2)\log \alpha = \log A_n - \log A_1 \qquad [1]$$

where N is the number of densities, α is a constant governing the rate of change of spacing, A_1 and An are the range of the area per plant;

$$\theta = T\,(\alpha - 1)/\sqrt{\alpha} \qquad [2]$$

where T is the rectangularity (intra/inter-row spacing) of plant arrangement and θ is the angle in raidians between radii; and

$$r_o = \sqrt{2A_1/\theta\,(\alpha^3 - \alpha\,)} \qquad [3]$$

where ro is the initial distance from the center apex of the "fan." Each other distance (arc) was calculated as follows:

$$r_n = r_o \alpha^n \qquad [4]$$

$$M \text{ to } M_1 = a \tan \theta \text{ and } M \text{ to } M_2 = a \tan 2\theta \qquad [5]$$

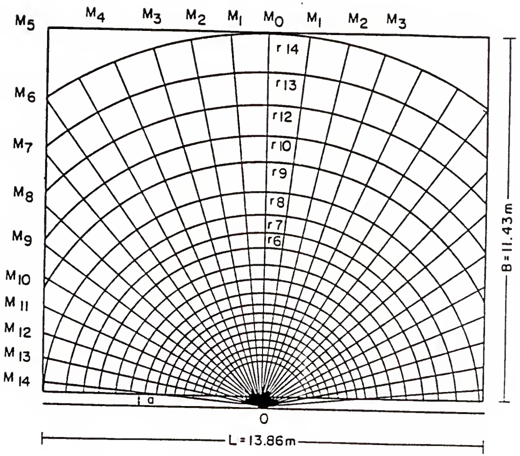


Fig. 1. Diagram of a "fan" design fitted into a rectangular plot. Each arc represents a different plant density, and the intersection with each radius represents a plant.

and so on, where a is the shortest distance from the center of the nearest side (base line) of the enclosing rectangle, and M is the point at which the central radius crosses the base line at right angle.

The values used for designing the fan in this study were: α = 1.111, A_1 = 0.10 m^2 $plant^{-1}$, A_n = 1.0 m^2 $plant^{-1}$, θ = 0.105 rad = 6.036°, τ = 1, r_o = 2.70 m, and a = 0.357 m. In addition, the following equations were developed to replace equation [5] to better enclose the "fan" into the rectangular plot (the value of "a" being too small)

$$M_o \text{ to } M_n = M_n = (B + a) \tan \theta_n \qquad \text{if } M_n < L/2 \qquad [6]$$

$$M_n = L/2 \tan (90 - \theta_n) - a \qquad \text{if } M_n > L/2 \qquad [7]$$

where L is the length of the plot (L = 13.86 m), B is the width of the plot (B = 11.43 m), and θ_n = nθ.

Each "fan" was replicated three times. The "fan" design consisted of 29 plants per density (arc) with two plants at each arc-end as borders. For border, two arcs at the lowest density and three arcs at the highest density were added to the 15 densities ranging from 0.80 to 15.4 plants m^{-2}.

Two maize kernels per hill were hand planted at each intersection of arcs and radii of the "fan" using a jab planter on 13 Mar. 1985 and 11 Apr. 1986. A pre-marked vinyl-covered wire was used to delineate the hills at the arc-radii intersection. Hills were thinned to one plant 14 days after planting (DAP).

Culture

Seedbed preparation was by mold-board plowing, tandem disking and rototilling to firm and smooth. Fertilization consisted of 112-26-100

kg ha^{-1} (N-P-K) disked in prior to planting. Additional fertilizers were applied as a side dressing prior to tasseling as follows: 200 kg ha^{-1} N (NH_4NO_3), 45 kg ha^{-1} K (KCl), and 45 kg ha^{-1} Mg ($MgSO_4$). In 1986, 16.8 kg ha^{-1} of Fenamiphos [ethyl 3-methyl-4-(methylthio) phenyl (1-methyl ethyl) phosphoriamidate] was disked in prior to planting for nematode control. Insecticides consisted of 2.34 L ha^{-1} of chlorpyrifos [O,O-diethyl O-(3,5,6-trichloro2-pyridyl)-phosphorothioate] sprayed one DAP and 6.6 ml L^{-1} of Methomyl [S-methyl-N-((methyl carbamoyl) oxy)-thioacetimidate] sprayed every 7 or 14 DAP, especially to control earworm (Heliothis armigera). Weeds were controlled by 2.34 L ha^{-1} of Metolachlor [2--chloro-N-(2-ethyl-6-methyl phenyl)-N-(2-methoxy-1-methyl ethyl acetamide] applied one DAP and by hoe 30 days after for the rest of the season. All plots were irrigated by a sprinkler system as required (25 mm) per application to alleviate moisture stress. Monthly mean temperature, precipitation, solar radiation, and the planting and harvesting dates for the 1985 and 1986 growing periods are shown in Tables 1 and 2, respectively.

Sampling

Three densities (1.9, 3.5, and 6.3 plants m^{-2}) were sampled beginning at 15 DAP for growth analysis in both 1985 and 1986. Measurements included leaf area index (LAI), leaf, stem, and stalk (leaf + stem) dry matter per plant. A LiCor (Model 3100) leaf-area meter was used to determine leaf area. Leaves and stems were separated, then dried at 70°C for 2 to 4 days, depending on the stage of maturity of the plant. Light was measured above the canopy and on the ground using LI-188B integrating Quantum/Radiometer/Photometer and

Table 1. Average monthly temperature, rainfall and solar radiation during the study period (March to December) of 1985 and 1986.

Month	Year	Maximum temperature	Minimum temperature	Rainfall	Solar radiation
		°C	°C	mm	E $m^{-2} day^{-1} (x10^{-3})$
Mar.	1985	27.07	11.48	34.79	12.57
	1986	24.47	9.27	90.17	13.08
Apr.	1985	27.75	13.60	119.38	13.03
	1986	28.30	10.88	16.00	18.83
May	1985	31.69	17.43	87.12	15.57
	1986	32.24	16.87	24.89	17.92
June	1985	33.52	21.87	164.08	15.04
	1986	33.24	20.87	143.51	15.77
July	1985	32.74	21.37	136.90	14.55
	1986	34.02	21.87	171.20	17.16
Aug.	1985	31.91	22.03	341.11	12.10
	1986	32.58	21.48	216.91	12.99
Sept.	1985	30.80	20.53	83.56	13.05
	1986	32.58	20.87	78.74	13.33
Oct.	1985	30.14	10.54	110.24	10.90
	1986	29.03	17.09	98.80	10.06
Nov.	1985	26.86	16.20	83.82	8.39
	1986	26.86	17.09	100.58	6.56
Dec.	1985	19.92	5.22	24.13	7.70
	1986	21.14	11.27	92.71	5.72

Source: Agronomy Farm Meteorological Weather Station, University of Florida, Gainesville.

Table 2. Planting and harvesting dates and duration cycles of intercrops maize/soybean.

Crops and cultivars	1985 Planting	1985 Harvesting	1985 Duration	1986 Planting	1986 Harvesting	1986 Duration
			days			days
Maize						
Pioneer '3192'	13 Mar.	15 July	124	11 Apr.	28 July	108
Soybean						
'Cobb' (MG VIII)	8 May	23 Oct.	168	12 May	17 Oct.	158
'Davis' (MG VI)	8 May	25 Sept.	140	12 May	29 Sept.	140
Maize/Cobb	--	--	224	--	--	189
Maize/Davis	--	--	196	--	--	171

LI-191SB quantum-line sensor. Light was also measured in the canopy at ground and ear levels, and below tassel near solar noon (SN), 5 h (SN-5h) and 3 h (SN-3h) before solar noon, and below tassel for all 15 densities at grain-filling period. Percent light interception (PLI) was determined as follows:

$$PLI = \frac{I_a - I}{I_a} \times 100 \qquad [8]$$

where I_a and I are the irradiance above canopy and at a given level in the canopy [below tassel (I_t), ear level (I_e), ground level (I_g) . . .], respectively.

Vertical leaf area distribution per volume of space at 30-cm increments of plant height and vertical light interception were also recorded. Plant height and number of tillers per plant were determined from five central-radii for all 15 densities at physiological maturity. Crop growth rate (CGR) was computed as the slope of the linear portion of the growth curve of dry matter (DM) accumulation per unit area.

Statistical Analysis

Analysis of variance (ANOVA) and, when appropriate, regression analysis were used to analyze data. Differences among treatment means were compared using Duncan's multiple range test (DMRT) or least significant difference (LSD) at 0.05 probability level. All analyses were carried out according to SAS (Statistical Analysis Systems, 1979) procedures.

Results and Discussion

Light Interception

Effect of time of measurement

Light interception measurements at 5 and 3 h before solar noon (SN-5h, SN-3h) and at solar noon (SN) were similar for each maize density at ground and ear levels and below tassels (Fig. 2), indicating the efficacy of a range of morning times for light interception measurements. This finding contrasts the commonly held view that measurement should be made at solar noon. Evening measurements were not made since they should mirror the morning ones. At some lowest plant densities (1.2, 1.5, and 1.9 plants m^{-2}) light interception below canopy (ground level) at SN was generally lower than at early hours (SN-5h and SN-3h), as might be expected since this maize cultivar had erectophile leaves, especially above the ear, and as such would accommodate more sun radiation penetration at SN; or conversely more extinction at lower solar angles than at SN (approximately 90°). Light interception values were similar for the three times of measurement, except at the density of 3.5 plants m^{-2} at which light interception at SN-3h was significantly less than at SN and SN-5h.

At the below-tassel level (10 to 20 cm canopy depth), light interception increased more gradually from 3.5 to 40% on the average over the range of the 15 plant densities (Fig. 2, Table 3). But below tassel measurements were generally more erratic than those of deeper canopy levels.

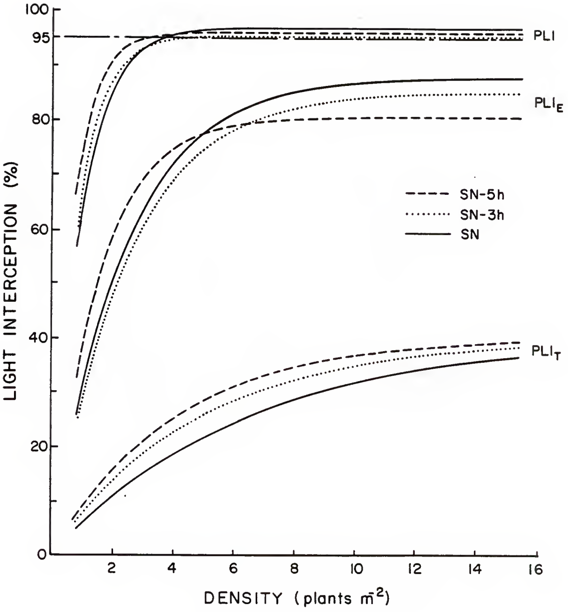


Fig. 2. Relationship between light interception and maize density, at solar noon (SN), 3 and 5 hours before solar noon (SN-3h and SN-5h), measured below tassel (PLI_T), at ear level (PLI_E), and ground level (PLI), during grain filling phase.

Table 3. Predictive equations from regression analysis relating light interception below tassel (PLI_T), at ear level (PLI_E), at ground level (PLI), measured at solar noon (SN), 3 and 5 hours before solar noon (SN-3h and SN-5h), with maize plant density (Xm).

Canopy level	Day-time	Equations
PLI_T	SN-5h	$y = 40.00\ (1-e^{-0.243Xm})$
	SN-3h	$y = 40.00\ (1-e^{-0.205Xm})$
	SN	$y = 40.00\ (1-e^{-0.154Xm})$
PLI_E	SN-5h	$y = 80.58\ (1-e^{-0.654Xm})$
	SN-3h	$y = 85.26\ (1-e^{-0.418Xm})$
	SN	$y = 88.15\ (1-e^{-0.430Xm})$
PLI	SN-5h	$y = 95.80\ (1-e^{-1.444Xm})$
	SN-3h	$y = 95.29\ (1-e^{-1.241Xm})$
	SN	$y = 96.47\ (1-e^{-1.076Xm})$

<u>Effect of canopy depth</u>

Vertical light distribution in maize canopy is presented in Fig. 3. Light interception was 83 to 93% at ear level (90 cm) and increased only slightly with greater canopy depth, especially in the medium (3.5 plants m^{-2}) and high (6.3 plants m^{-2}) density. This suggests that light necessary for maximum grain yield accumulation was captured above ear at the higher densities. At low density (1.9 plants m^{-2}) only 50% of the incident radiation was captured at ear level and light interception significantly increased with canopy depth to ground level.

Approximately 40, 30, and 2% of light was intercepted at 10 to 20 cm canopy depth (below tassels and flag leaves) at the high, medium, and low density, respectively. This is consistent with earlier reports (Duncan et al., 1967; Williams et al., 1968) that tassels probably do not contribute appreciably to photosynthesis, yet intercept significant amounts of light. Tassels remain an obstruction to the free penetration of light into the foliage canopy below. Also Grogan et al. (1961) reported a positive grain yield response by detasseling and the increase was greater at high than at low plant densities.

<u>Effect of plant density</u>

Maize plant density influenced canopy light interception significantly (Fig. 4). As early as 35 DAP, light interception by maize canopy was 40, 60, and 75% for the low (1.9), medium (3.5), and high (6.3 plants m^{-2}) density, respectively. These results are

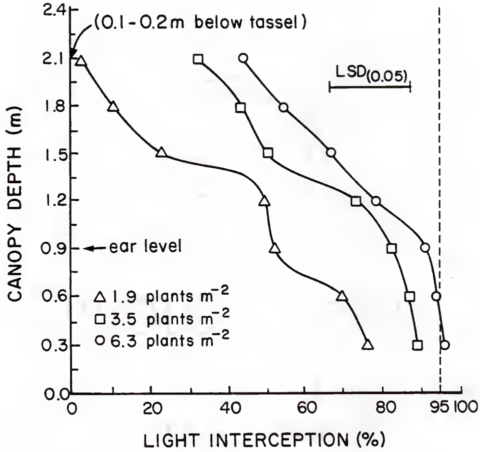


Fig. 3. Influence of plant density on vertical light interception in maize canopy.

important for timing of intercropping maize with short-statured crops, especially at densities above 3.5 plants m^{-2} in which less than 40% light penetrated the canopy. At 63 to 70 DAP (silking to grain-filling), 95% of the incident light was intercepted by both 3.5 and 6.3 densities, reflecting canopy closure and maximum efficiency of radiant energy use in photosynthesis. However, the low density never reached the 95% light interception level (critical light interception). The light interception by the medium density was not significantly different from that of the high density.

Light interception peaked between 77 and 84 DAP for all densities, which corresponded to the milk and dough stages (R_3 and R_4), when the rate of dry matter accumulation was most rapid, and also when LAI stopped increasing.

Vegetative Growth

Vertical leaf distribution

Leaf area distribution in space for three densities (1.9, 3.5, and 6.3 plants m^{-2}) is shown in Fig. 5. At 90 and 120 cm depth (ear level), the 6.3 plant density significantly increased the leaf area distribution compared to the 1.9 and 3.5. There was disproportionately greater leaf area produced at the ear level of the high density. At low and medium plant densities, leaf area was more uniformly distributed vertically. The dispersion of leaf area in space and time is an important factor in the management of crop production, especially intercropping. The leaf area concentration

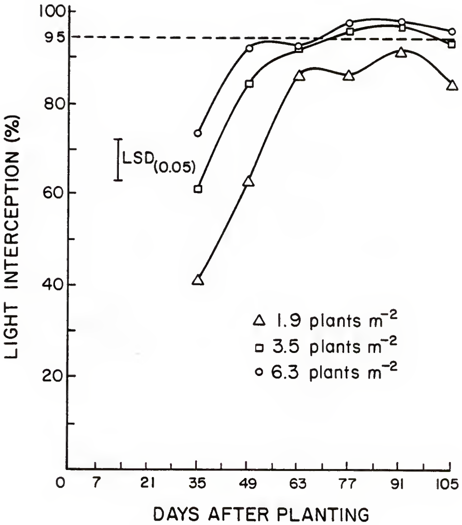


Fig. 4. Influence of plant density on sequential light interception in maize.

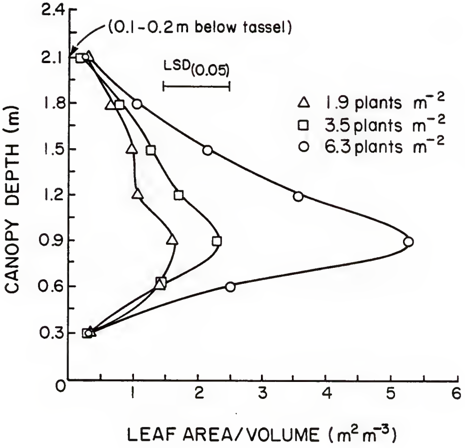


Fig. 5. Influence of plant density on vertical distribution of leaf area in maize canopy during the grain filling phase.

around ear level explained the high light interception obtained at this level, and is consistent with earlier results (Loomis et al., 1968). Loomis et al. reported a maximum leaf area at the ear stratum for all densities studied, and attributed the reduction of leaf area in the lower strata at high densities to senescence of older leaves. Fresh and healthy leaf area concentration around the ear, the locus of dry matter accumulation as grain, is necessary and should be a high priority management goal for optimum maize yield.

Leaf area index (LAI)

Accumulation of LAI followed a similar pattern for all three densities (Fig. 6). Leaf area index increased significantly with increasing plant density. A maximum LAI of 1.7, 2.6, and 4.0 was obtained for 1.9, 3.5, and 6.3 plants m^{-2}, respectively, at 63 DAP, but declined thereafter. The high plant density was three times greater than the low, but its LAI was less than three times greater than that of the low density. The peak LAI corresponded to nearly 95% light interception for the medium and high density, but to less than 95% for the low density. Therefore, the critical LAI (Brougham, 1956) for the medium and high densities fell between 2.6 and 4.0. The critical LAI was not reached by the low density. Pearce et al. (1965) and Williams et al. (1968) reported a direct relationship between LAI and light interception, resulting in increased photosynthesis up to a critical LAI value. In general, photosynthesis increases until nearly all incident solar radiation is intercepted by photosynthetic surfaces. Any further increase in leaf area only increases shading of

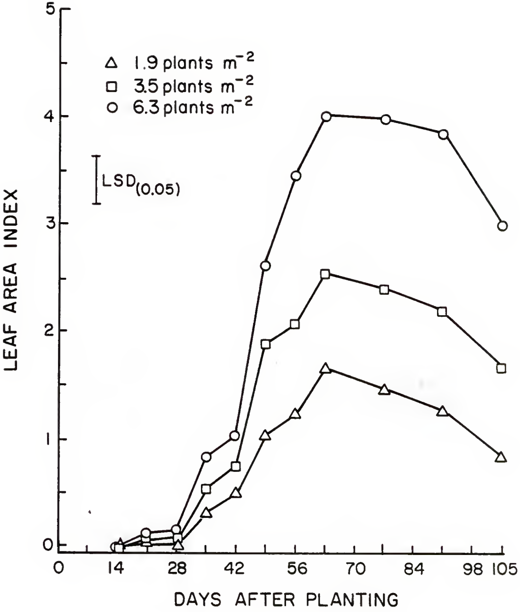


Fig. 6. Influence of plant density on leaf area index accumulation in maize, mean of 1985 and 1986.

the lower leaves with little benefit to the plant (Gardner et al., 1985).

Dry matter accumulation

Plant density affected dry matter accumulation significantly in the leaf, stem, and stalk (leaf + stem) (Fig. 7). Different plant parts followed a similar growth pattern throughout the growing period. Leaves and stem growth did not differ significantly until 49 DAP, thereafter; stem gradually accounted for more than 50% of the stalk dry weight. After about 70 DAP, leaf and stem gradually lost dry weight by mobilization and redistribution to grain, but the stem lost was most pronounced. After flowering (63 DAP), the monocarpic maize plant is completely in its reproductive phase and therefore is partitioning assimilate to grain (Gardner et al., 1985). Leaf, stem, and stalk dry weight did not differ significantly among the three densities until after 49 DAP, which indicates the beginning of inter-plant competition, resulting in 20 to 50% less yield per plant for each component from the medium and high density treatments.

Crop growth rate

Crop growth rate (CGR) of maize was significantly affected by plant density (Table 4). The high plant density (6.3) accumulated 41.6 and 103.5% more dry matter per unit area per day than the medium (3.5) and the low (1.9 plants m^{-2}) density, respectively. The higher CGR obtained at high density was closely related to greater light interception (above).

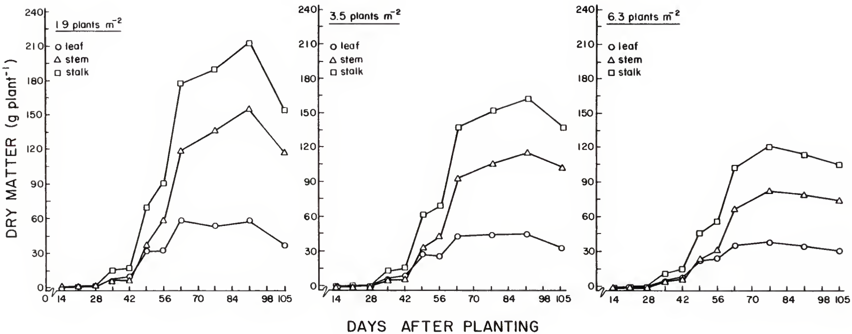


Fig. 7. Leaf, stem, and stalk (leaf + stem) dry matter accumulation in maize at three densities (1.9, 3.5, and 6.3 plants m^{-2}).

Table 4. Crop growth rate (CGR) as influenced by plant density in maize, mean of 1985 and 1986.

Plant density	CGR
m^{-2}	$g\ m^{-2}\ day^{-1}$
1.9	14.2 c
3.5	20.4 b
6.3	28.9 a
LSD (0.05)	3.4

Means followed by the same letters are not significantly different ($P < 0.05$) according to Duncan's multiple range test.

Plant height

Plant height increased parabolically with increasing plant density (Fig. 8). It peaked between 6 and 10 plants m^{-2}, then declined thereafter, which is similar to the trend reported by Stinson and Moss (1960), and Early et al. (1966) as a result of mutual shading. Internode plant elongation (etiolation) is a well-known phenomenon. This shade effect is believed to be due to auxin acid (GA). Theoretically, photodestruction of auxin is less in shaded stands, since high irradiance decreases auxin and plant height (Leopold and Kriedemann, 1975). However, the decrease of plant height at ultra-high densities is probably associated with severe competition for other factors such as nutrient and water, which, added to the light reduction in the lower canopy, are inhibitory to stem growth.

Tillering

The number of tillers per plant decreased linearly as density increased up to 3.5 plants m^{-2}, then ceased thereafter (Fig. 9). The formation of tillers appeared to be very much controlled by the environment. In 1985, few tillers were produced, even at low plant densities, but in 1986, the early season high radiation and water supply, added to nitrogen application, promoted the tillers' formation, but at the expense of the third ear on the main stem. A third ear was prevalent at low densities in 1985.

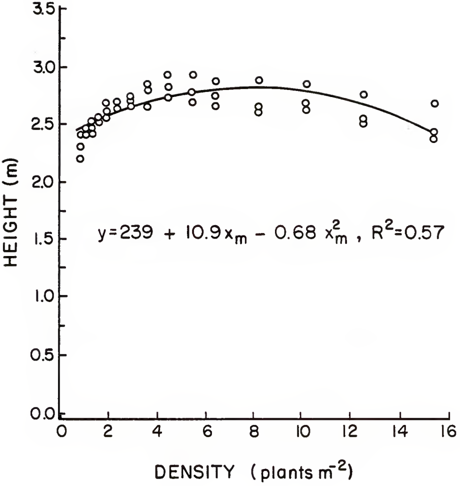


Fig. 8. Relationship between maize plant height and density (Xm).

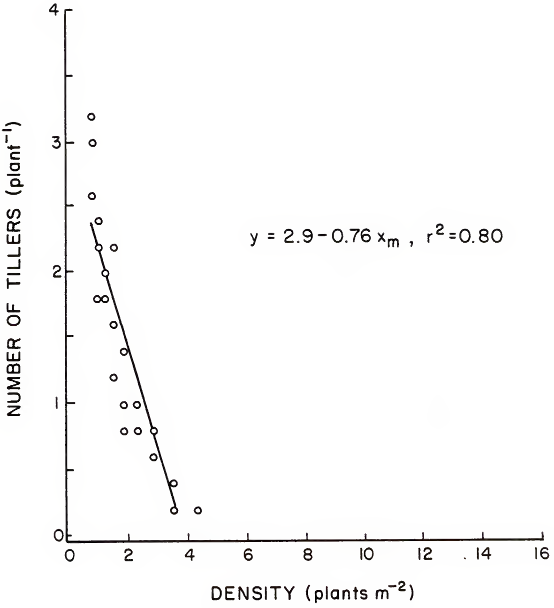


Fig. 9. Relationship between the number of tillers per plant and the density in maize (restricted only to densities where the tillers were produced).

CHAPTER III
MAIZE RESPONSES TO PLANT DENSITY: INFLUENCE ON REPRODUCTIVE DEVELOPMENT, YIELD AND YIELD COMPONENTS

Introduction

Plant density is the primary cause of interplant competition affecting vegetative and reproductive growth parameters. Plant population can be defined not only in terms of the number of plants per unit area (plant density) but also in terms of the arrangement of the plants for a given area (spatial arrangement) (Willey and Heath, 1970).

Maize (Zea mays L.) reproductive growth responses to plant density have generally shown that individual plant yield decreased with increasing plant density (Duncan, 1958). Prior and Russell (1975) reported an increase in mean kernel yield of maize with densities up to 51,000 plants ha^{-1} then a decrease to 72,000 plants ha^{-1}. Plant population influences ear weight more than hybrid vigor or nitrogen level of the soil (Lang et al., 1956). Each reduction in population density increased ear weight and kernel number but decreased yield per plant (Baenziger and Glover, 1980). Tsai and Chung (1984) obtained a maximum maize kernel yield of 15 tons ha^{-1} at 62,500 plants ha^{-1}. Number of ears per plant decreased linearly as the plant population increased whereas the ear weight response was curvilinear (Karim et al., 1983). Kernel-row number in hybrids did

not change with planting density from 16,300 to 46,900 plants ha^{-1} (Stringfield and Thatcher, 1947). In relating ear proliferation to plant density, Bauman (1960) indicated that wider-row spacings compared to narrow rows gave greater frequency and size of second ears, and therefore, a larger second-ear per plant.

Most studies on effect of plant density on maize reproductive growth have used a limited range of plant densities. Also, plant density and spatial arrangement (density distribution) effects are usually confounded. Details on how individual maize plants respond to population, by changes in partitioning of dry weight and morphology, for example, have been scarcely considered (Carberry et al., 1985).

This study was then designed to observe the effect of a wide range of plant densities on reproductive characters that influence maize yield.

Materials and Methods

Field experiments were conducted on the Agronomy Farm at the University of Florida, Gainesville, during the 1985 and 1986 growing seasons. The soil, a Lake fine sand (hyperthermic, coated Typic Quartzipsamments) had a Melich I extractable test of 105 ppm of P, 60 ppm of K, 28 ppm of Mg, 300 ppm of Ca, and a pH of 6.1. The design and culture were as described in Chapter II.

Sampling

Reproductive growth was followed by weekly sampling of the ear and total (biomass) dry matter per unit area at three densities (1.9, 3.5, and 6.3 plants m^{-2}). Fifteen plant densities ranging from 0.80

to 15.4 plants m^{-2} were harvested from the five central radii of the "fan" at physiological maturity as determined by occurrence of kernel black layer on 15 July 1985 and 28 July 1986. Plants were cut at ground, separated into ears and stalks (leaves and stems), and then dried at about 40°C to 13% moisture for kernels. Stalks were dried at 70°C until their weight remained constant.

Final measurements included percentage of 1-, 2-, and 3-eared plants; kernel-row number per ear (KRNE), kernel number per row (KNR), kernel number per ear (KNE), weight per kernel (WK), and average weight per kernel per plant (AWK), distribution of kernel dry weight to ear 1 (top), ear 2, and ear 3; stalk dry matter, kernel yield, and total dry matter per plant and per unit area; distribution of ear dry matter to husk, cob, and kernel; shelling percentage (SHP) [kernel dry weight/(kernel + cob) dry weight x 100]; harvest index (HI) (kernel yield/total dry matter). Average weight per kernel per plant (AWK) was calculated as follows:

$$AWK = \frac{(KNE_1 \times WK_1) + (KNE_2 \times WK_2) + (KNE_3 \times WK_3)}{KNE_1 + KNE_2 + KNE_3}$$

where subscripts 1, 2, and 3 refer to ears 1, 2, and 3.

Statistical Analysis

Regression was the primary analysis but, when appropriate, covariance analyses were used also according to SAS (Statistical Analysis System, 1979). Regressions of all measurements per plant or per individual unit with plant density were carried out using Bleasdale's (1967b) model

$$(\omega^{-\theta} = \alpha + \beta\rho) \qquad [1]$$

where ω is the mean yield response per plant, ρ is the number of plants per unit area; α and β are the parameters having a constant value for sets of data where ρ was the only variable; and θ is a parameter having a constant value for any one set of data. For the following data, $\theta = 1$.

Results and Discussion

Yield Components

Ear number

Ear number per plant (ENP) varied with plant density (0.8 to 15.4 plants m^{-2}) from 1 to 3 ears in 1985 but 1 to 2 ears in 1986 (Table 5). The cutoff (complete ear lost) of the third ear in 1986 at the lowest density might have been caused by the following: (a) 30-day delay in planting date in 1986 and resultant longer daylength during the vegetative period, and/or (b) a greater proportion of the total nitrogen application made at seeding in 1986, which might have promoted a shift to tillers at the expense of the third ear. The number of ears per plant (1985) decreased from 3 to 1 over the range of 2.3 to 15.4 plants m^{-2}, i.e., 1 ear was maintained at the ultra-high density (15.4 plants m^{-2}). Two-eared plants were 100% up to 2.3 plants m^{-2}, then decreased gradually to 40% at 3.5 plants m^{-2} and cutoff thereafter. Three-eared plants comprised 40% of plants at the lowest density (0.8 plants m^{-2}), then declined to about 7% at 2.3 plants m^{-2}, and 0% thereafter. In 1986, 2-eared plants were 100% up to 1.5 plants m^{-2}, but gradually decreased to only about 7% at the cutoff (3.5 plants m^{-2}).

Table 5. Influence of plant density on ear proliferation in maize, 1985 and 1986.

Plant density	Percentage of plants with at least 1 ear		at least 2 ears		at least 3 ears	
	1985	1986	1985	1986	1985	1986
m^{-2}	%					
0.8	100	100	100	100	40.0	0
1.0	100	100	100	100	13.0	0
1.2	100	100	100	100	6.6	0
1.5	100	100	100	100	6.6	0
1.9	100	100	100	86.6	6.6	0
2.3	100	100	100	80.0	6.6	0
2.8	100	100	86.6	26.6	0	0
3.5	100	100	40.0	6.6	0	0
4.3	100	100	0	0	0	0
5.4	100	100	0	0	0	0
6.3	100	100	0	0	0	0
8.2	100	100	0	0	0	0
10.2	100	100	0	0	0	0
12.5	100	100	0	0	0	0
15.4	100	100	0	0	0	0

Harris et al. (1976) suggested that certain lower ears abort because they reach the silking stage in poor synchronism with upper ears. Environmental conditions determine the size as well as the number of second ears (Bauman, 1960). Plant density effect through shading likely is an important factor controlling ear proliferation, and was responsible for failure of ear development with increasing plant densities. Prior and Russell (1975) used high plant density as a method to screen and evaluate for hybrid maize proliferation.

Kernel-row number per ear

Kernel-row number per ear (KRNE) and other parameters discussed hereafter were nearly identical for the 2 years. Therefore, the data were merged and only means are discussed.

Kernel-row number per ear of the first ear (ear 1, top) decreased linearly only slightly (0.14 row per 1 plant m^{-2} increased in density) over the 15-plant density range (Table 6, Fig. 10). The kernel-row number of the second ear (ear 2) was not significantly different from ear 1 until 2.3 plants m^{-2}, but declined thereafter to 0.0 at 4.3 plants m^{-2}. The third ear (ear 3) was significantly different from ear 2 and ear 1 in KRNE and decreased drastically (74%) as plant density increased up to the cutoff point of 2.3 plants m^{-2}.

Kernel number per row

Kernel number per row (KNR) was in the following order: ear 1 > ear 2 > ear 3 (Table 6). Ear 1 maintained the constant number (42-45) to about 3.5 plants m^{-2} but declined gradually (46%) thereafter

Table 6. Influence of plant density on kernel-row number per ear (KRNE), kernel number per row (KNR), and kernel number per ear (KNE) distributed to top (ear 1), second (ear 2), and third ear (ear 3) in maize, mean of 1985 and 1986.

Plant density	KRNE			KNR			KNE		
	Ear 1	Ear 2	Ear 3	Ear 1	Ear 2	Ear 3	Ear 1	Ear 2	Ear 3
m^{-2}	No.								
0.8	15.8	15.2	13.5	45.2	37.2	26.7	717.0	564.6	360.5
1.0	15.0	14.5	5.5	45.2	37.9	14.7	677.6	547.1	80.0
1.2	15.3	15.2	7.0	45.5	37.4	12.0	697.0	564.8	84.0
1.5	15.3	15.0	7.0	44.6	33.4	11.0	683.6	492.5	77.0
1.9	14.8	14.6	7.0	43.6	33.1	11.0	645.6	481.8	77.0
2.3	15.0	13.8	7.0	44.5	26.7	10.0	665.2	370.6	70.0
2.8	14.5	13.4	0	43.9	28.2	0	634.6	379.9	0
3.5	15.5	11.2	0	41.8	19.6	0	647.4	262.7	0
4.3	14.8	0	0	40.0	0	0	590.7	0	0
5.4	15.2	0	0	38.1	0	0	577.1	0	0
6.3	14.6	0	0	37.7	0	0	549.9	0	0
8.2	14.0	0	0	31.8	0	0	445.1	0	0
10.2	14.0	0	0	27.6	0	0	387.4	0	0
12.5	14.0	0	0	24.7	0	0	345.0	0	0
15.4	13.0	0	0	24.2	0	0	314.7	0	0
Percent reduction	17.7	26.3	48.1	46.5	47.3	62.5	56.1	53.5	80.6

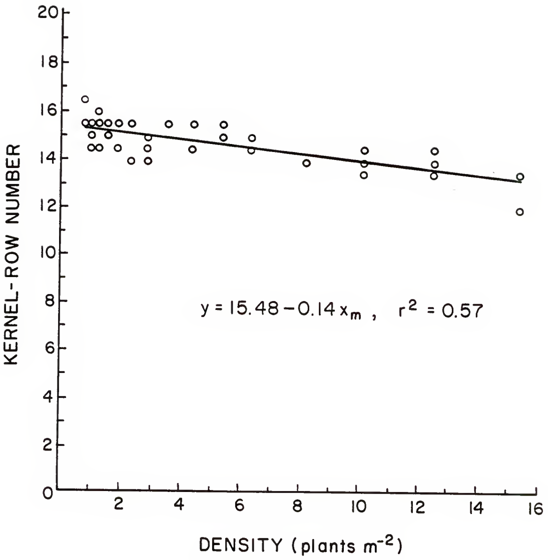


Fig. 10. Relationship between kernel-row number of the top ear (ear 1) and plant density in maize, mean of 1985 and 1986.

to 24.2 kernels per row at 15.4 plants m^{-2}. Ear 2 maintained a constant KNR only up to 1.2 plants m^{-2} then declined gradually (47%) to 19.6 at 3.5 plants m^{-2}, the cutoff. Ear 3 declined by 81% from 0.8 to the cutoff density (2.3 plants m^{-2}).

Kernel number per ear

Kernel number per ear (KNE) followed the same pattern as KNR, ear 1 > ear 2 > ear 3 (Table 6). The percentage reduction in KNE was in the same proportion and the cutoff points in ear 2 and ear 3 the same as in KNR and KRNE. This should be expected since KNE is a function of KNR and KRNE.

The reduction (mean of the ear 1, 2, and 3) due to plant density was 66, 58, and 39% for KNE, KNR, and KRNE, respectively.

Kernel number per plant and per unit area

Kernel number per plant decreased (79%) reciprocally over the 15-plant density range in a reciprocal relationship, whereas kernel number per unit area increased (197%) parabolically with increasing plant density (Fig. 11), i.e., yield increased per unit area 2.5 times faster than yield loss per plant.

Weight per kernel

Weight per kernel (WK) was not affected by plant density for ear 1 and for ear 2 until about the cutoff (Table 7), i.e., the response of ear 1 over the range of density was at a constant linear rate of zero (Fig. 12). However, weight per kernel of ear 3 was significantly lower than that of ear 1 and ear 2, and the reduction due to density

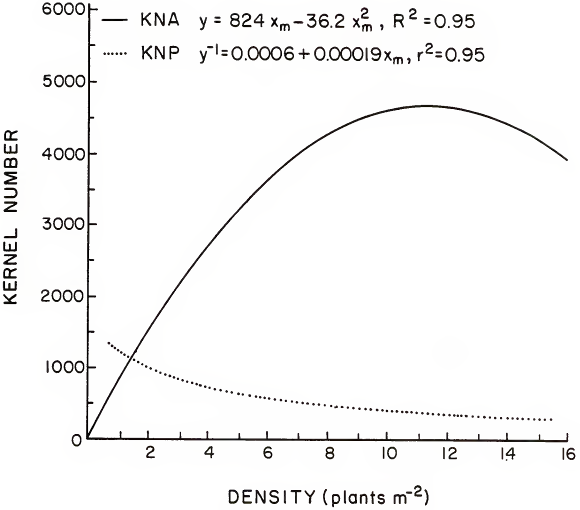


Fig. 11. Relationship between kernel number per plant (KNP), kernel number per unit area (KNA), and plant density in maize, mean of 1985 and 1986.

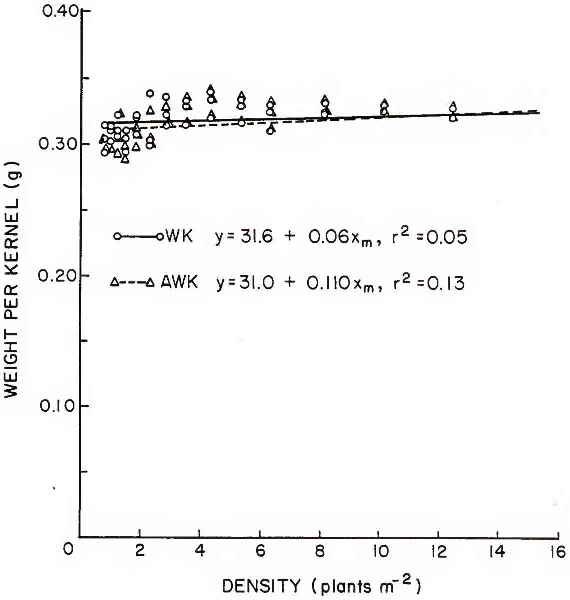


Fig. 12. Relationship between weight per kernel (WK) of the top ear (ear 1), average weight per kernel (AWK) of the plant and plant density in maize, mean of 1985 and 1986.

was more pronounced and immediate with increasing plant density greater than 0.8 plants m^{-2}. This illustrated the high vulnerability of ear 3 KW to increasing plant density as contrasted to low vulnerability for ear 1 and 2.

Weight per kernel (mean of ear 1, 2, and 3) had no response to plant density, the slope of which was not significantly different from zero (Fig. 12). The constancy of weight per kernel over increasing density indicates the small effect of this component in yield adjustment in maize.

Ear and Kernel Yield

The sequential harvest for growth analysis showed that ear dry matter (EDM) accumulation began at 56 DAP and continued at an approximate constant rate through 91 DAP at a 1.9 plants m^{-2} density and through 105 DAP for the higher densities (Fig. 13), indicating an earlier maturity for the low density. Senescence in the field, based on leaf greenness, was visually hastened by low density, or conversely delayed by high density. Earlier maturation may have potential advantage for marginal adaptation in temperate zones and for understory crops in intercropping systems. Ear yield (in the sequential harvest of three densities) was in the order of 6.3 > 3.5 > 1.9 plants m^{-2}, but the yield difference narrowed as density increased, suggesting a quadratic response to plant density.

Over the 15 densities range harvested at maturity, kernel yield increased parabolically, reaching a maximum of 1080 g m^{-2} at about 10

Table 7. Influence of plant density on the top (ear 1), second (ear 2), and third ear (ear 3) weight per kernel in maize, mean of 1985 and 1986.

Plant density	Weight per kernel		
	Ear 1	Ear 2	Ear 3
m^{-2}	g (x 10^{-2})		
0.8	30.5	29.0	20.6
1.0	31.0	30.5	15.6
1.2	31.3	30.0	10.0
1.5	30.3	29.0	10.3
1.9	31.6	29.5	10.3
2.3	31.4	30.3	11.0
2.8	32.5	31.1	0
3.5	32.6	26.4	0
4.3	33.1	0	0
5.4	32.8	0	0
6.3	32.2	0	0
8.2	32.6	0	0
10.2	32.8	0	0
12.5	32.4	0	0
15.4	30.8	0	0

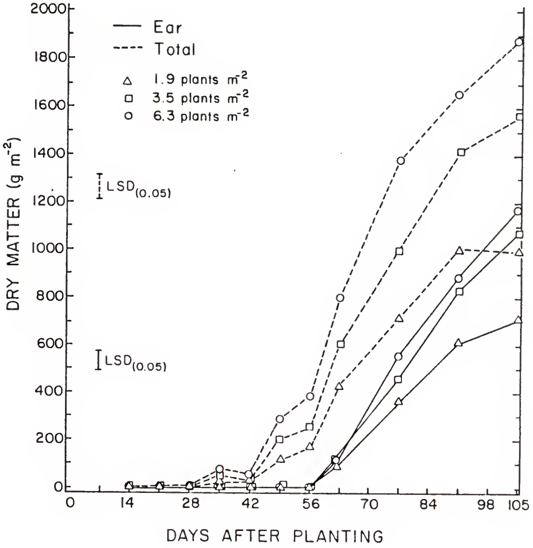


Fig. 13. Ear (husk + cob + kernel) and total (leaf + stem + ear) dry matter accumulation in maize as affected by plant density (1.9, 3.5, and 6.3 plants m^{-2}), mean of 1985 and 1986.

plants m^{-2}, in both 1985 and 1986 (data merged) (Fig. 14). An optimum of 10 plants m^{-2} is considerably higher than that previously reported, which generally was from 5 to 6.5 plants m^{-2} (Lang et al., 1956; Prior and Russell, 1975; Tsai and Chung, 1984). This disparity is probably a result of the experimental design used. This study employed the "fan" design which is characterized by equidistant spacing (squareness or rectangularity of 1.0) regardless of plant density, contrasted to a row arrangement (squareness decreased with plant density, since inter-row spacing remained constant in most cases) in the other studies. Parvez et al. (in press) showed that optimum density increased with increasing squareness (intra/inter-row spacing).

Kernel yield per plant decreased reciprocally with increasing plant density (Fig. 14).

Total and Stalk Dry Matter Yield

In sequential harvest for growth analysis, total (leaf + stem + ear) dry matter (DM) yield increased with plant density at a nearly constant rate from 42 DAP through 91 DAP, after which the low density plateaued (Fig. 13).

Over the 15-densities range at final harvest, total and stalk DM yield increased asymptotically with increasing plant density (Fig. 14). The yield asymptotes corresponded to about 12.5 plants m^{-2} for both total and stalk DM. It is apparent that maize plant density greater than about 12 plant m^{-2} would not produce further forage yield increase of economic significance.

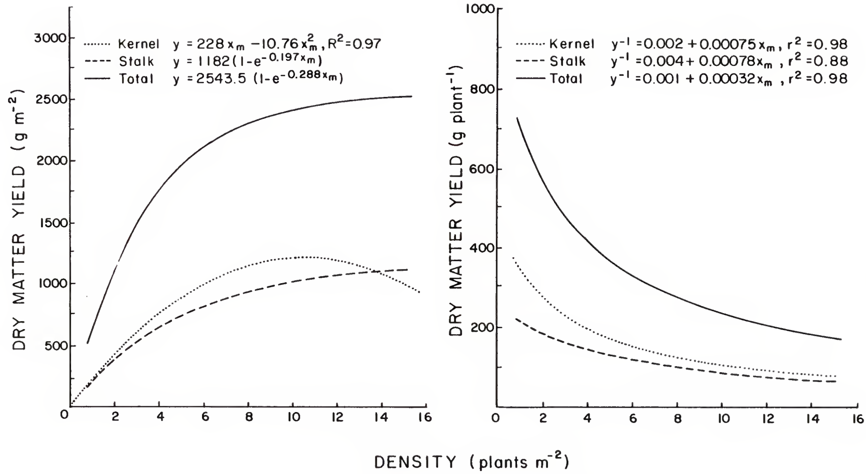


Fig. 14. Relationship between dry matter (stalk, kernel, and total) yield per plant and per unit area and plant density (Xm) in maize, mean of 1985 and 1986.

Total and stalk DM yield per plant decreased with increasing plant density, in agreement with the findings reported by Duncan (1958). A reciprocal function described best this relationship (Fig. 14). Shinozaki and Kira (1956), Bleasdale (1967a), and Willey and Heath (1970) pointed out that a reciprocal function best described plant-parts-yield-density relationships, which is of primary importance agronomically.

Assimilate Distribution

Plant-ear ratio

Significant difference in DM percentage in ears among the three densities sequentially harvested began at 63 DAP and continued for the sampling period in the order of 1.9 > 3.5 > 6.3 plants m^{-2}. The percentage of total plant DM in the ear increased from about 20 to 70% from 63 to 105 DAP for the 1.9 and 3.5 plant densities, compared to about 14 to 62% for the 6.3 density for the same period (Table 8). The consistently lower ear-ratio indicates a lower partitioning coefficient or harvest index in the high density (6.3 plants m^{-2}). However, ear yield for 1.9, 3.5, and 6.3 plants densities increased 648, 799, and 978%, respectively, from 63 (silking) to 105 DAP, the grain filling period, indicating that the increase in plant density more than compensated for the loss in partitioning coefficient.

Ear priority

Over the 15-densities at the final harvest, the distribution priority within each plant was in the order of ear 1 > ear 2 > ear 3 (Fig. 15). This priority increased for ear 1 and decreased for ears 2

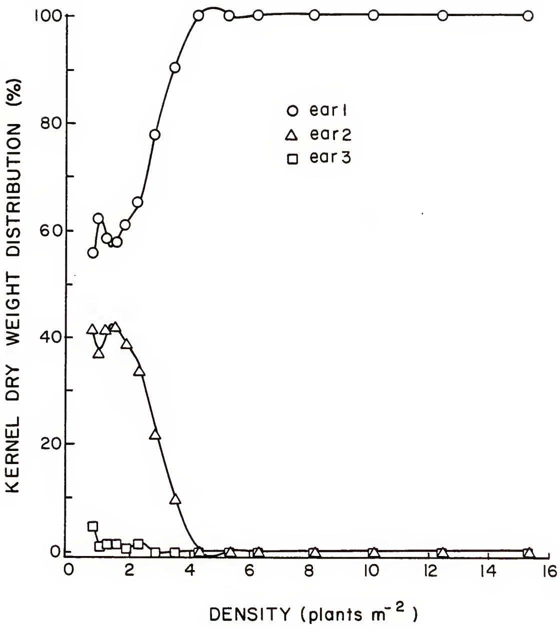


Fig. 15. Influence of plant density on kernel dry weight distribution to the top (ear 1), the second (ear 2), and the third ear (ear 3) in maize, mean of 1985 and 1986.

Table 8. Dry matter present in the maize ear as percentage of total dry matter at three densities and four sequential sampling dates, mean of 1985 and 1986.

Plant density	Ear dry matter fraction at days after planting				% Increase (63-105 DAP)
	63	77	91	105	
m^{-2}	%				
1.9	22.1	49.8	60.2	70.9	647.8
3.5	19.4	45.6	58.8	68.3	799.3
6.3	13.6	40.4	53.5	62.3	977.7

and 3 with increasing plant density. The apical dominance of the top ear has been reported by Bauman (1960), who demonstrated that, in addition to apical dominance, the top ear showed the ability to grow larger than the second ear. Kernel development and starch deposition are slightly later in the second ear (Harris et al., 1976). Harris et al. further stated that apical dominance is itself a controversial subject.

Yield component vulnerability and yield adjustment

Yield components vulnerability to plant density was as follows: ENP > KNE > KNR > KRNE > WK according to covariance analysis (Table 15), since ear 2 or ear 3 kernels lost some dry weight before the ear cutoff by density. This suggests that as the density pressure is gradually removed, yield adjustment occurs first by changes in ENP, followed by KNE, KNR, KRNE, and WK. Krishnamurthy et al. (1975) and Hall et al. (1981) indicated that the number of kernels per ear is the yield component of maize which is most environmentally sensitive.

The increase in plant number up to a maximum more than compensated for the decreases in ears per plant and kernel number per ear and the per plant decrease in total, stalk, and kernel yield. The extent of compensation is seen in Table 9, which shows kernel to husk + cob ratio increased with increasing plant density. At extremely low densities, there was no major adjustment in ENP, WK, KRNE, KNR, and KNE to compensate for changes in plant density, hence, less internal competition for assimilate, and yield is essentially a linear function of plant density. As density is increased competition for assimilate is increased and adjustment in yield components is in the order

Table 9. Influence of plant density on the fraction of ear dry matter (DM) present in husk, cob, and kernel, and on kernel/(husk + cob) ratio (KHCR), on shelling percentage (SHP), and harvest index (HI) in maize, mean of 1985 and 1986.

Plant density	Ear DM distribution Husk	Cob[a]	Kernel	SHP[b]	HI[c]	KHCR
m^{-2}	%					ratio
0.8	10.9	10.6	78.5	81.7	49.5	3.9
1.0	10.3	12.4	77.2	76.7	46.8	3.7
1.2	10.1	9.9	79.9	83.5	50.2	4.3
1.5	10.2	10.5	79.3	82.2	51.3	4.1
1.9	10.1	10.4	79.5	82.6	50.9	4.2
2.3	9.7	10.0	80.2	82.7	50.1	4.4
2.8	9.7	10.1	80.2	82.4	48.4	4.4
3.5	8.9	12.0	79.0	80.8	45.6	4.0
4.3	8.0	10.2	81.7	82.5	46.1	5.0
5.4	7.4	10.0	82.6	83.4	47.6	5.3
6.3	7.1	11.5	81.3	81.2	44.8	4.8
8.2	6.7	10.4	82.8	82.3	45.5	5.4
10.2	6.9	10.6	82.5	81.9	46.2	5.3
12.5	6.8	10.6	82.5	82.2	45.0	5.3
15.4	6.9	10.3	82.8	82.6	44.3	5.4

[a] cob = ear − (husk + kernel)

[b] $SHP = \frac{\text{kernel DM}}{\text{(kernel + cob) DM}} \times 100$

[c] $HI = \frac{\text{kernel yield}}{\text{Total DM yield}} \times 100$

discussed. The relationship becomes quadratic. Poneleit and Egli (1979) and Baenziger and Glover (1980) reported that the maize plant can more readily adjust its yield by changes in kernel number than by changes in weight per kernel.

Plant density had no significant effect on ear dry matter partitioning to cob and kernel, but DM partitioned to husk decreased gradually from about 1.9 to 15.4 plants m^{-2}. However, this loss in husk was somewhat balanced by a slight increase in kernel DM over the density range (Table 9), in agreement with Allison's (1969) findings, that the fraction of ear consisting of grain increased with density. On the average, 9, 8, and 75% of the ear DM was allocated to husk, cob, and kernel, respectively.

Shelling percentage and harvest index

Shelling percentage (SHP) was constant over the plant density range, whereas harvest index (HI) decreased slightly but not significantly with increasing plant density (Table 9). On the average, 47% of the total DM was accounted for by kernel DM. These results, in addition to those of ear DM distribution suggested that the prolific maize hybrid '3192' used in this study is highly allometric.

CHAPTER IV
MAIZE/SOYBEAN INTERCROPPING AND PLANT DENSITY: INFLUENCE ON GROWTH AND YIELD

Introduction

Intercropping systems have been practiced for centuries in much of the world, especially in the tropics. Intercropping can increase crop diversity, biological stability of the ecosystem, and labor efficiency, while at the same time reducing soil erosion and the occurrence of risks (Norman, 1974; Ruthenberg, 1976; Okigbo, 1979; Beets, 1982). It facilitates multiple crop production, thereby making more efficient use of the seasonal rainfall, nutrient and solar radiation (Ruthenberg, 1976, ICRISAT, 1976). It indicates the minimum potential of each intercrop growing under competition with minimum inputs, which may be of particular interest to plant breeders. Intercropping is important in the temperate regions and has become a subject of interest to ecologists, physiologists, economists, nutritionists, and social scientists (Francis, 1985).

Because of the extreme number of biologic, climatic, edaphic, cultural, and social elements that constitute the complex environment which fosters intercropping use, understanding of various systems is incomplete and numerous problems need resolution. For most maize (*Zea mays* L.)/legume intercropping studies, maize is the aggressor component. In Uganda, Willey and Osiru (1972) found that maize had stronger competitive ability than bean (*Phaseolus vulgaris* L.).

Negative correlations between bean and maize yields were reported in Costa Rica (Hart, 1975). In intercropping maize and soybean [<u>Glycine max</u> (L.) Merr.] in Minnesota, Crookston and Hill (1979) found that yields of soybean were always reduced whereas maize yields were even improved in some combinations. Dalal (1977) reported a large yield reduction in soybean planted with maize even in alternate pairs of rows. Up to 87% reduction in soybean yield was reported by Chui and Shibles (1984).

More research is needed on plant density combinations of the intercrops and their spatial arrangements that will optimize production efficiency and indicate compatible genotypes. Until something is known about the plant density/spacing requirements, it is difficult to plan a meaningful research on other aspects such as genotype identification (ICRISAT, 1977). Many plant density studies have been carried out for various purposes such as replacement series approach (Willey, 1979b), interactions of density (Francis et al., 1982). It is important, when considering research goals, to determine if sub-optimum density is a real constraint on the producer (Baker and Francis, 1985). There is a tendency to overseed the cereal component in order to reduce poor germination risks. This practice, in addition to the use of tall perennial crops such as coffee, increases both intra and interplant competition. Therefore it becomes necessary to know how much of a tall companion crop such as maize can be seeded to allow an acceptable yield of the understory legume such as soybean, a new crop in numerous tropical areas, which remains to be incorporated in the whole cropping system.

To observe the growth and development of soybean and yield of both soybean and maize in order to determine the maize plant density range that is complementary to the maize/soybean intercrop, we therefore interplanted constant plant densities of soybean across a wide range of maize densities.

Materials and Methods

Field experiments were conducted on the Agronomy Farm at the University of Florida, Gainesville, during the 1985 and 1986 growing seasons. The soil, a Lake fine sand (hyperthermic, coated Typic Quartzipsamments), had a Melich I extractable test of 105 ppm of P, 60 ppm of K, 28 ppm of Mg, 300 ppm of Ca, and a pH of 6.1.

Design

The design for both sole and intercropped maize was as described in Chapter II. The two determinate soybean cultivars used were 'Davis' [maturity group (MG VI)] and 'Cobb' (MG VIII). The sole soybean "fan" (as described by Nelder, 1962) contained a total of 43 densities (arcs) ranging from 1.3 to 107.1 plants m^{-2} with a 9.4% increment between densities. The plants were spaced at a constant rectangularity of 2. Each "fan" was split in half with 14 radii per cultivar. Four were harvested for final yield. Both low and high densities were bordered by three arcs; therefore 37 densities ranging from 1.76 to 77.3 plants m^{-2} constituted the harvested area of the "fan." The dimensions of the "fan" were determined using Bleasdale's equations ([1], [2], [3], and [4]) as described in Chapter II: α = 1.054, A_1 = 0.028 m^2 plant $^{-1}$, An = 0.555 m^2 plant^{-1}, T = 2, θ = 0.105

rad = 6.036°, and ro = 2.10 m. Each "fan" was inclosed in a rectangular plot using equations [6] and [7] (Chapter II).

For the intercropped soybean, the plant densities were 1.8, 3.0, 5.1, 8.5, 14.3, and 24.0 plants m^{-2} in 1985. 3.0, 8.5, and 24.0 plants m^{-2} in 1986. The following equation was developed in order to calculate the change in soybean stands necessary for a constant rate relative to maize densities in the "fan" (Figs. 16, 17):

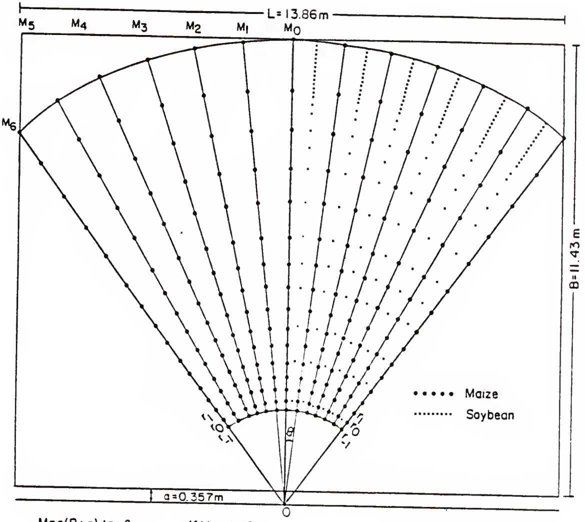
$$dn = \sqrt{[(2n-1)(\theta P)^{-1} + d_o^{\,2}]} \qquad [1]$$

where dn is the planting stand of the n^{th} soybean plant(s) between maize radii, θ is the angle between maize radii, P is the given constant soybean density, and do = ro = 2.70 m as calculated from Bleasdale's (1967b) equation.

Each of three replicates contained eight "fans" (1 sole maize, 1 sole soybean, and 6 intercrops) in 1985. There were five "fans" (1 sole maize, 1 sole soybean, and 3 intercrops) in 1986.

Culture

The planting and harvesting dates for both maize and soybean are presented in Table 2. Seeding and crop maintenance were as described in Chapter II. In addition, soybean seeds were pretreated with a mixture of Captan [cis-N-(trichloromethyl)thio-4- cyclohexene-1,2-dicarboximide] and carboxin (5,6-dihydro-2 methyl-N-phenyl-1,4-oxathiin-3-carboximide).



$M_n = (B+a)\tan\theta_n$, if $M_n < L/2$

$M_n = L/2 \tan(90-\theta_n) - a$, if $M_n > L/2$

$\theta_n = n\theta$

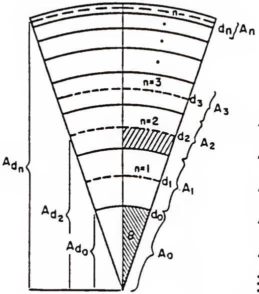
$r_0 = \sqrt{\dfrac{2A_1}{\theta(a^3-a)}} = 2.70\text{m}$

$r_n = r_0\, a^n$

$\theta = r(a-1)/\sqrt{a} = 6.036°$

$a = 1.111$

Fig. 16. Diagram of a fan showing intercrops maize and soybean arrangement. The intercrop soybean density is maintained constant in a fan while maize density increases toward the fan apex.



$$= \frac{A_2}{2} = \frac{1}{2}\left(\frac{1}{P}\right)$$

$$A_0 = A_{d_0} = d_0^2\pi\left(\frac{\theta}{2\pi}\right) = d_0^2\frac{\theta}{2} \Rightarrow A_{d_n} = d_n^2\frac{\theta}{2} \quad [1]$$

$$A_1 = A_2 = A_3 = \dots = A_n = \frac{1}{P} \quad [2]$$

$$A_{d_1} = d_0^2\frac{\theta}{2} + \frac{A_1}{2} = d_0^2\frac{\theta}{2} + \left(1\frac{1}{P} - \frac{1}{2}\frac{1}{P}\right)$$

$$A_{d_2} = d_0^2\frac{\theta}{2} + A_1 + \frac{A_2}{2} = d_0^2\frac{\theta}{2} + \left(2\frac{1}{P} + \frac{1}{2}\frac{1}{P}\right)$$

$$A_{d_3} = d_0^2\frac{\theta}{2} + A_1 + A_2 + \frac{A_3}{2} = d_0^2\frac{\theta}{2} + \left(3\frac{1}{P} + \frac{1}{2}\frac{1}{P}\right)$$

$$\vdots$$

$$A_{d_n} = d_0^2\frac{\theta}{2} + A_1 + A_2 + \dots + \frac{A_n}{2} = d_0^2\frac{\theta}{2} + \left(n\frac{1}{P} + \frac{1}{2}\frac{1}{P}\right)$$

$$A_{d_n} = d_0^2\frac{\theta}{2}\left(n - \frac{1}{2}\right)\frac{1}{P} \quad [3]$$

$$[1] = [3] \Rightarrow \boxed{d_n = \sqrt{(2n-1)(\theta P)^{-1} + d_0^2}}$$

Fig. 17. Diagram used to develop the equation dn, which allows the planting of intercrop soybean at a constant density in a fan; dn is the distance from the fan apex representing each intercrop soybean plant.

Sampling

In both 1985 and 1986, 15 maize densities (0.80 to 15.4 plants m^{-2}) were sampled for kernel yield and total dry matter per plant and per unit area, and the 37 sole soybean densities (1.76 to 77.3 plants m^{-2}) were sampled for seed yield (SY) and total dry matter (TDM) per plant and per unit area.

For each intercropped soybean density, 12 to 15 samples were collected corresponding to 12-15 maize densities along the radius. Measurements included seed yield and total dry matter per plant and per unit area. In addition, biweekly harvest for growth analysis was carried out for the 24.0 plants m^{-2} intercrop soybean in both 1985 and 1986, at three intercrop maize densities (1.9, 3.5, and 6.3 plants m^{-2}). The 24.0 plants m^{-2} sole soybean was also growth analyzed as control. Sampling started 15 days after soybean planting and continued until about soybean maturity, which occurred after the maize was removed. Measurements included leaf area index (LAI) and dry matter (DM) accumulation. A LiCor (model 3100) leaf area meter was used to determine the leaf area. Leaves and stems were separated then dried at 70°C for 3 days. Crop growth rate (CGR) was computed using the linear portion of the growth curve of dry matter accumulation, which began before and continued after the maize removal (BMR and AMR).

Statistical Analysis

Regression analysis, covariance analysis, and analysis of variance were used to analyze the data. Treatment means were separated using Duncan's multiple range test (DMRT) or least

significant difference (LSD) at 0.05 probability level. All analyses were carried out according to SAS (Statistical Analysis Systems, 1979). Regression of all measurements per plant on density were computed using the following model proposed by Bleasdale (1967b):

$$- \quad = \quad + \quad ,$$

and described in Chapter III.

Results and Discussion

Maize Yield

Maize yield and other parameters discussed hereafter were nearly identical for both years (the year x treatments interaction was not significant, $P < 0.05$). Therefore, the data were merged and only 2-yr means are discussed.

In general, maize yield was not significantly affected by the intercrop soybean (Fig. 18, Appendix Table 18). Kernel yield of both sole and intercrop maize for all six soybean densities (Fig. 18, Table 16) increased parabolically up to a maximum of 1080 to 1200 g m^{-2} with increasing maize plant density to about 10 plants m^{-2}, and declined thereafter.

Total dry matter (TDM) yield increased asymptotically with increasing maize plant density for both the sole and the intercrop maize (Fig. 18, Table 17). The asymtotes were 2450 to 2890 g m^{-2}, which occurred at about 12.5 plants m^{-2}. It is significant to note that maximum TDM yield occurred at about 2.5 plants m^{-2} higher density than that for kernel yield. Over the 15-density range, maize kernel yield increased by 313 and 322% for the sole and intercrop,

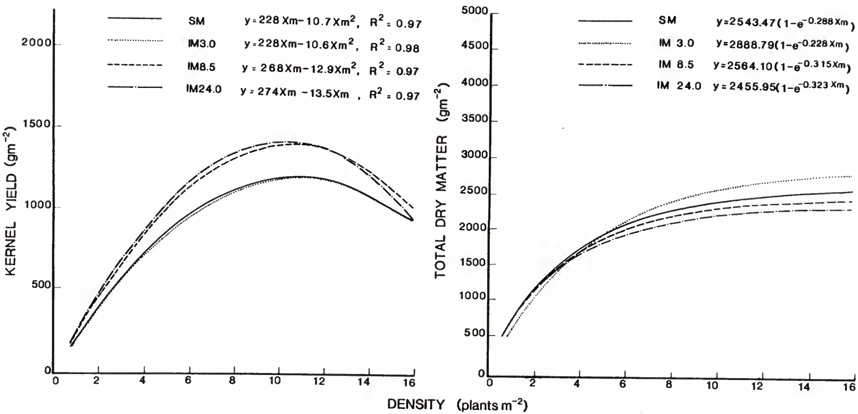


Fig. 18. Relationship between kernel and total dry matter yield per unit area of solecrop (SM) and intercrop maize (IM) at three soybean densities (3.0, 8.5, and 24.0 plants m^{-2}), and maize plant density (Xm), mean of 1985 and 1986.

respectively. Total dry matter yield increased by 379 and 397% for sole and intercrop, respectively. Kernel yield per plant was reduced by 78.5 and 78% and TDM per plant by 75 and 74% per plant for the sole and intercrop, respectively.

Kernel and TDM yield per plant for the sole and intercrop maize decreased as a reciprocal function of maize plant density (Fig. 19). The overall means kernel yield of the intercrop maize, compared to sole, was slightly, though non-significantly, increased (2%). These results contrast with some earlier reports (Nnko and Doto, 1980) which showed that yield of intercrop maize planted with soybean 1 week later was lower than the sole crop checks. Another study showed that maize yield was reduced 20 to 50% when intercropped with soybean, bean, or cowpea (Edje and Laing, 1980; Gamma and Thiruketheeswaran, 1984; Akanda and Quayyum, 1982). However, maize yield was not affected by associated soybeans or cowpeas (Singh, 1977; Mongi et al., 1980; Serpa et al., 1981), furthermore; maize yield was reported to have increased 20 to even 100% when intercropped with soybean (Ibrahim et al., 1977; Crookston and Hill, 1979; Galal et al., 1980). The focus was earlier put on the transfer of nitrogen from the legume to the nonlegume as a way of explaining these intercrop yield responses (Agboola and Fayemi, 1971; Finlay, 1974). It is likely that there are more factors such as allelopathy, change in the microclimate and especially rhizosphere environments, stimulation of soil microorganisms, mutual defense from predators, weeds, or disease organisms, which are yet to be explored for better understanding of the interaction between intercrop species.

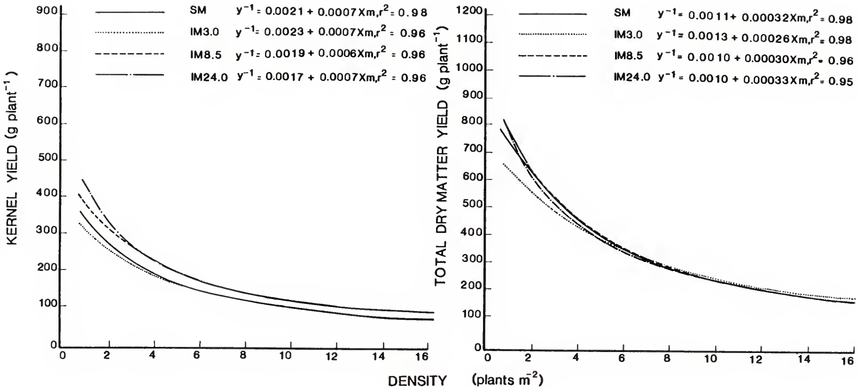


Fig. 19. Relationship between kernel and total dry matter yield per plant of solecrop (SM) and intercrop maize (IM) at three soybean densities (3.0, 8.5, and 24.0 plants m^{-2}), and maize plant density (Xm), mean of 1985 and 1986.

Rose et al. (1984) pointed out that soybean root exudates may be able to retard weed growth long enough for the soybean to establish a canopy to shade weeds. Thompson (1977) and Willey (1979a) suggested that the depletion of nitrogen by the cereal caused an increase in nitrogen fixation by stimulation of nodule number and weight.

Soybean Growth

Leaf area index

Leaf area index (LAI) of the Cobb and Davis cv. was reduced significantly by both intercropping and as maize density increased (Fig. 20, Table 20). In intercropping, LAI of Cobb was similar to Davis until the maize was removed (70 DAP), corresponding to R_3 for Davis and R_1 to R_2 for Cobb, the late cultivar, which demonstrated some recovery potential and regrowth. In sole cropping, after the maize was removed, Cobb LAI was also similar to Davis until later in the season. Thus, maize pressure appears more pronounced on Davis, the earlier cultivar. The effect of intercropping on LAI was significant as early as 28 DAP for both cultivars. Thereafter, LAI gradually increased up to a maximum at 98 DAP, except for the intercrop Cobb under 6.3 maize plants m^{-2} (IS 6.3) which reached its maximum 112 DAP. Maximum LAIs for Cobb were 9.97, 4.35, 2.11, and 0.88, compared to Davis's maxima of 7.84, 4.35, 2.11, and 0.81, for SS, IS 1.9, IS 3.5, and IS 6.3, respectively. The reduction due to intercropping increased with increasing maize density (36, 63, and 91% for Cobb compared to 44, 73, and 90% for Davis, at 1.9, 3.5, and 6.3 maize plants m^{-2}, respectively). The pattern of LAI accumulation was

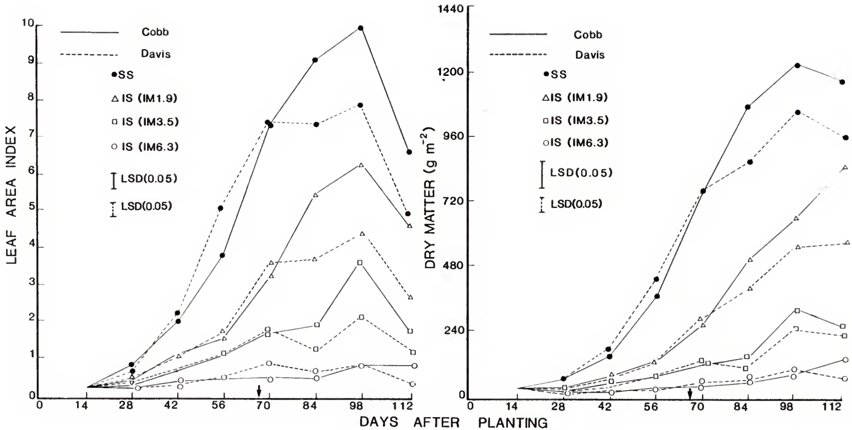


Fig. 20. Leaf area index and dry matter accumulation of two soybean cultivars (Cobb and Davis) at 24.0 plants m^{-2} in sole (SS) and intercropping (IS) under three intercrop (IM) densities (1.9, 3.5, and 6.3 plants m^{-2}). The arrow indicates the date of maize removal.

in agreement with those reported earlier (Shibles and Weber, 1965; Weber et al., 1966; Buttery, 1969). However, the LAI under high maize density (6.3 plants m^{-2}) exhibited almost a constant linear pattern over time and is considered extremely low. The companion maize crop at this density almost completely suppressed the LAI accumulation in these soybean cultivars and below that necessary to carry out photosynthesis and sustain growth. After maize was removed, the late cultivar continued leaf growth for a short time but the new growth was too late for yield adjustment. These results indicate that timing of planting is an important factor and that late cultivars fit better into an intercropping system such as the one used in this study.

Dry matter yield

Dry matter (DM) accumulation followed the same pattern as LAI, except for IS 1.9 and IS 6.3 in Cobb which kept increasing (Fig. 20), resulting from regrowth, as discussed earlier. Maximum DM accumulations were obtained 98 DAP. Thereafter, DM declined, at a rate faster in sole than in intercropping. Significant differences between sole and intercrop DM accumulation were observed 14 DAP compared to 28 DAP for LAI. At maximum production (98 DAP) DM accumulation in Cobb was reduced by 47, 74, and 94% in intercropping compared to 48, 77, and 91% in Davis, under 1.9, 3.5, and 6.3 maize plants m^{-2}, respectively, again demonstrating the extreme pressure on soybean growth by maize at high (6.3) and even medium (3.5) densities. In some cases, DM accumulation even declined after maize removal at high density before slightly increasing, suggesting a readaptation to full sunlight.

Crop growth rate

Crop growth rate (CGR) was greatly affected by intercropping and maize density for both Cobb and Davis (Table 10). In general, the two cultivars did not differ significantly in CGR. The sole crop CGR obtained (about 17 g m^{-2} day^{-1} for both cultivars) agrees with earlier reports for soybean (Hanway and Weber, 1971; Egli and Leggett, 1973). The consistently significant difference between CGR after maize removal (AMR) and BMR in both cultivars only indicates the normal growth process in the sole crop where soybean was approaching its maximum growth at decreasing rate. In intercropping, CGR BMR was reduced by 67, 86, and 97% for Cobb, and by 62, 83, and 96% for Davis under 1.9, 3.5, and 6.3 maize plants m^{-2}, respectively. The only significant difference between BMR and AMR occurred at 3.5 maize plants m^{-2} for Cobb indicating some advantage of the late cultivar over the early one provided the maize density is only moderately high. At 1.9 maize plant density, growth was essentially normal, while at the 6.3 plant density, soybean growth was very suppressed.

Soybean Yield

Sole soybean

Over the 37 plant density range (1.8 to 77.5 plants m^{-2}), seed yield increased with increasing plant density, almost linearly up to about 25.0 plants m^{-2}, then at decreasing rate up to a maximum of 547.3 g m^{-2} at 46.2 plants m^{-2} for Cobb, and 390.9 g m^{-2} at 41.5

Table 10. Crop growth rate (CGR) of two sole (SS) and intercrop soybean (IS) cultivars (Cobb and Davis) at 24.0 plants m^{-2} under three maize plant densities (1.9, 3.5, and 6.3 plants m^{-2}), before and after maize removal (BMR and AMR), mean of 1985 and 1986.

Cropping patterns	Maize density	CGR			
		Cobb		Davis	
		BMR[a]	AMR[b]	BMR	AMR
	plants m^{-2}	g m^{-2} day^{-1}			
SS		16.94 a A*	9.06 a B	16.60 a A	8.80 a B
IS	1.9	5.63 b A	7.61 ab A	6.25 b A	8.34 a A
IS	3.5	2.41 b B	10.71 a A	2.88 b A	8.42 a A
IS	6.3	0.48 b A	1.38 b A	0.73 b A	2.26 a A

*Means followed by the same lower-case letters in the same column and by the same upper-case letters in the same row within the same cultivar, are not significantly different ($P < 0.05$) according to Duncan's multiple range test.

[a]BMR is 67 days and

[b]AMR is 90 and 65 days of Cobb and Davis growth, respectively.

plants m^{-2} for Davis, thereafter starting to decline, resulting in a parabolic response relationship (Fig. 21). The lowest yield obtained at the lowest densities were 136.1 and 103 g m^{-2} for Cobb and Davis, respectively. On the average, Cobb yielded about 35% more than Davis. Most earlier studies have shown that maximum soybean yields are obtained between 20 and 40 plants m^{-2} (Maia et al., 1982; Lamera and Pava, 1983; Wright et al., 1984; Parvez et al., in press). More recently, Herbert and Litchfield (1984) reported a 27% increase in soybean seed yield by increasing plant density from 25 to 80 plants m^{-2}, with no further increase beyond the highest density.

Seed yield per plant decreased with increasing plant density in a reciprocal relationship (Fig. 21). From the lowest (1.8) to the highest density (77.5 plants m^{-2}), yield ranges were 80.7 to 5.7 and 55.6 to 3.1 g $plant^{-1}$ for Cobb and Davis, respectively, resulting in nearly the same reduction for Cobb (93%) and Davis (94%).

Total DM yield, which included only stems and pods at maturity, increased asymptotically with increasing plant density (Fig. 22). The asymptotes were 1110.3 and 775.4 g m^{-2} for Cobb and Davis, occurring at about 37.5 and 27.2 plants m^{-2}, respectively. These densities may be considered as the upper density limits for soybean production, beyond which no further TDM yield increase would be obtained.

Total DM yield per plant followed the same pattern as seed yield per plant (Fig. 22). The reduction in yield per plant from the lowest to the highest density was nearly the same for Cobb (92%) and Davis (93%). This suggests that plant density may not be the factor responsible for the lower seed yield in Davis. Therefore,

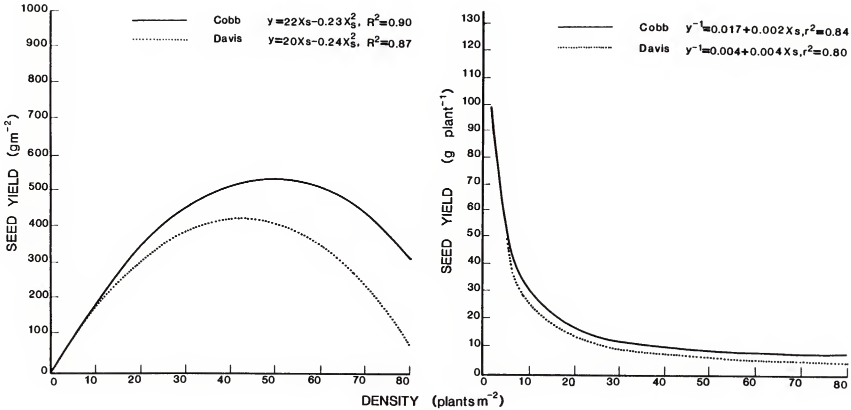


Fig. 21. Relationship between seed yield per plant and per unit area of two solecrop soybean cultivars (Cobb and Davis), and soybean plant density (Xs), mean of 1985 and 1986.

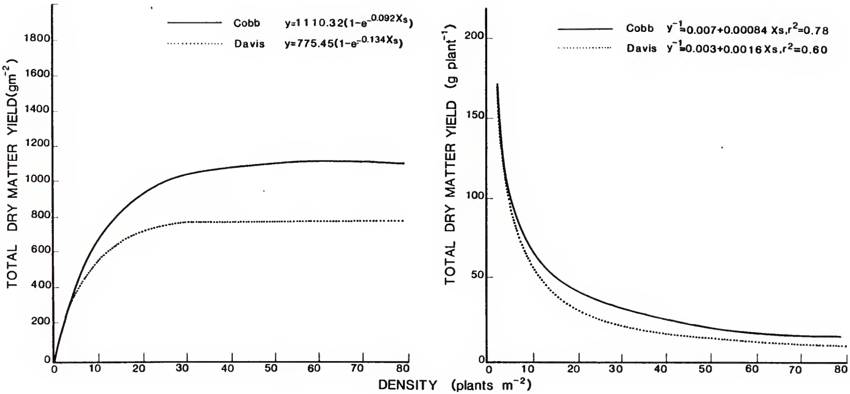


Fig. 22. Relationship between total dry matter yield per plant and per unit area of two solecrop soybean cultivars (Cobb and Davis), and soybean plant density (Xs), mean of 1985 and 1986.

plant-density response cannot be used to screen these two cultivars. Other factors such as the length of the growing period should be considered.

Intercrop soybean

Seed yield decreased with increasing maize density for all six intercrop soybean densities (IS 1.8 to IS 24.0), in a reciprocal relationship (Fig. 23, Tables 22, 23, and 24). The highest intercrop soybean seed yield was obtained from the highest soybean plant density (IS 24.0), which was followed by IS 14.3 = IS 8.5 > IS 5.1 = IS 3.0 = IS 1.8 for Cobb and IS 24.0 = IS 14.3 > IS 8.5 > IS 5.1 > IS 3.0 > IS 1.8 for Davis. These differences were more pronounced with Cobb, which yielded significantly more than Davis. There was no significant cultivar x intercrop soybean density and maize density x intercrop soybean density interactions. At lowest maize density (< 1.0 plant m^{-2}), intercropping reduced soybean yield by 0 to 20% compared to 74 to 96% at highest maize density (> 6.0 plants m^{-2}) (Table 11). The aggressiveness of maize on intercrop soybean has been reported frequently (Singh, 1977; Nnko and Doto, 1980; Allen and Obura, 1983; Chui and Shibles, 1984). In mixtures, increasing cereal densities increased cereal yields but caused a progressive decrease in legume yields (Agboola and Fayemi, 1971; Syarifuddin et al., 1974). Yield loss may be overcome by growing crops differing in growth habits (Agboola and Fayemi, 1971). This indicates that light is the primary factor responsible for the reduction of intercrop soybean yield. Wahua and Miller (1978) observed also that there was a reduction

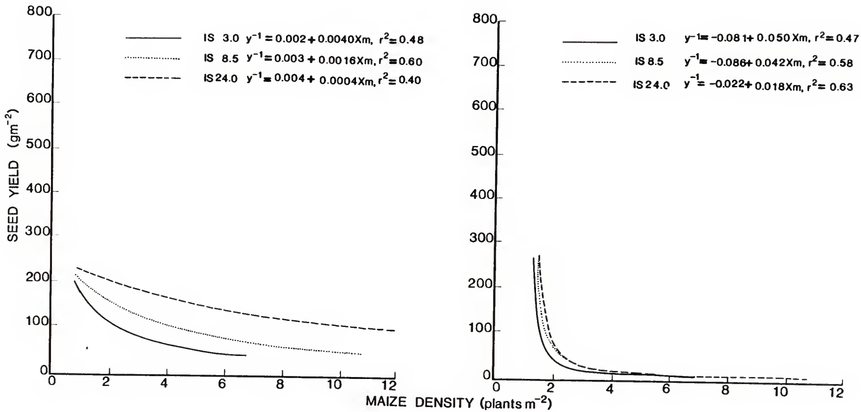


Fig. 23. Relationship between seed yield per unit area of two intercrop soybean (IS) cultivars (Cobb and Davis) at three densities (3.0, 8.5, and 24.0 plants m^{-2}), and maize plant density (Xm), mean of 1985 and 1986.

Table 11. Seed yield of two intercrop soybean cultivars (Cobb and Davis) as affected by two extreme maize densities (low and high), mean of 1985 and 1986.

Soybean density	Maize density	Cobb Seed yield Sole	Cobb Seed yield Intercrop	Cobb % Change[a]	Davis Seed yield Sole	Davis Seed yield Intercrop	Davis % Change
plants m^{-2}		g m^{-2}	g m^{-2}		g m^{-2}	g m^{-2}	
1.8	L[b]	142.1	140.2	- 1.3	97.9	124.6	+27.3
	H	142.1	24.6	-82.7	97.9	2.4	-97.5
3.0	L	157.3	167.7	+ 6.6	127.8	123.7	- 3.2
	H	157.3	39.3	-75.0	127.8	3.8	-97.0
5.1	L	198.6	189.5	- 4.6	180.7	169.7	- 6.1
	H	198.6	50.1	-74.8	180.7	5.9	-96.7
8.5	L	274.4	216.4	-21.1	238.9	201.3	-15.7
	H	274.4	56.8	-79.3	238.9	3.3	-98.6
14.3	L	299.6	250.5	-16.4	265.3	306.9	+15.7
	H	299.6	106.2	-64.5	265.3	18.5	-93.0
24.0	L	356.4	314.8	-11.7	292.1	281.2	- 3.7
	H	356.4	117.4	-67.0	292.1	10.8	-96.3

[a]- = % reduction, + = % increase.

[b]L = low (< 1.0 plant m^{-2}), H = high (> 6.0 plants m^{-2}).

in soybean nodule formation and size as a result of shading. However, the cause and effect of this response in relation to seed yield is not well documented.

Seed yield per plant also decreased in a reciprocal relationship with increasing maize density for all intercrop soybean densities (Fig. 24, Tables 22, 23, and 24), but yield per plant was in the reverse order: IS 1.8 > IS 3.0 > IS 5.1 > IS 8.5 > IS 14.3 > IS 24.0. This indicates that individual intercrop plants are permanently under intra-and inter-specific competitive pressure, mostly due to plant density.

Total DM yield per unit area and per plant followed the same pattern as seed yield (Figs. 25 and 26). The intercrop maize and soybean plant density combination for optimum yield of either crop is somewhat controversial. Kamel et al. (1983) reported that highest soybean seed yields were obtained from a system consisting of 32 soybean plants m^{-2} combined with 0.8 maize plant m^{-2}, and that highest maize yields were obtained from 2.4 maize plants combined with 24.0 soybean plants. In this study, the intercrop maize yield was not affected. However intercrop soybean yield reduction varied from 0 to 100%, depending on maize plant density. Therefore, we considered the density of maize below which the intercrop yield of soybean is equal or greater than 25% of its sole crop as the "critical maize density" for intercrop soybean (CDm/s25) and found that for high intercrop densities (8.5, 14.3, and 24.0 plants m^{-2}) of Cobb, about 11 maize plants m^{-2} is the "critical density," whereas at low densities (1.8, 3.0, and 5.1 plants m^{-2}), about 5, 7, and 8 maize plants m^{-2},

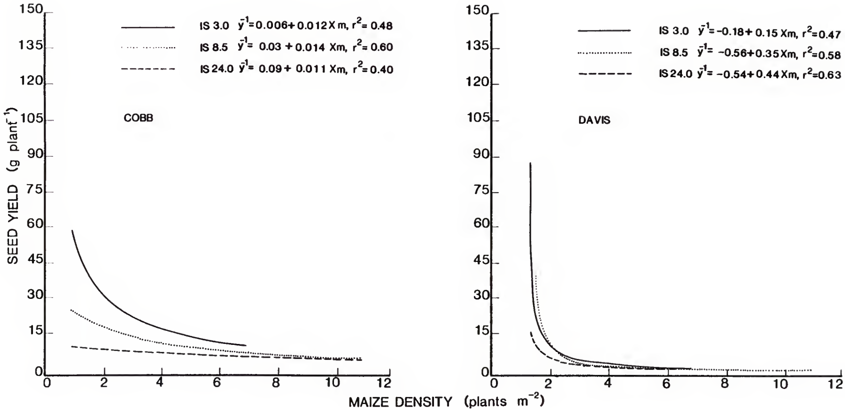


Fig. 24. Relationship between seed yield per plant of two intercrop soybean (IS) cultivars (Cobb and Davis) at three densities (3.0, 8.5, and 24.0 plants m^{-2}), and maize plant density (Xm), mean of 1985 and 1986.

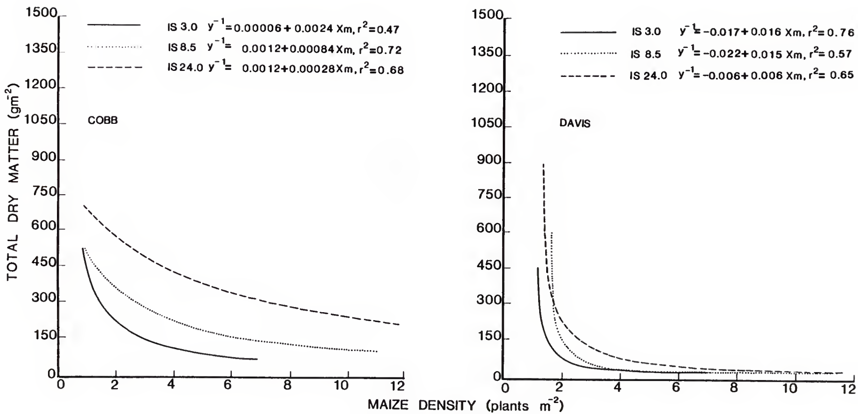


Fig. 25. Relationship between total dry matter yield per unit area of two intercrop soybean (IS) cultivars (Cobb and Davis) at three densities (3.0, 8.5, and 24.0 plants m^{-2}), and maize plant density (Xm), mean of 1985 and 1986.

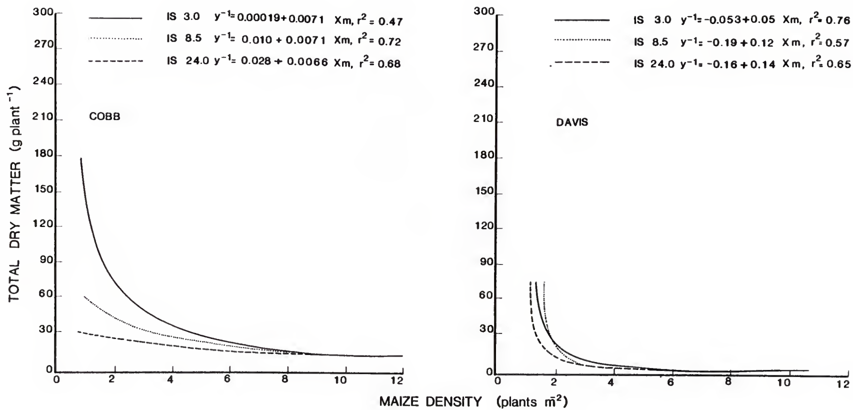


Fig. 26. Relationship between total dry matter yield per plant of two intercrop soybean (IS) cultivars (Cobb and Davis) at three densities (3.0, 8.5, and 24.0 plants m^{-2}), and maize plant density (Xm), mean of 1985 and 1986.

respectively, were the "critical densities." For Davis, the "critical maize density" was more uniform, 2 for the lowest intercrop soybean density (1.8 plants m^{-2}) and 3 to 4 maize plants m^{-2} for the rest (3.0, 5.1,, 8.5, 14.3, and 24.0 plants m^{-2}) (Table 12). Below these "critical densities," any combination could be considered depending on the goals and available resources of the growers, whose main objective may be maize and/or soybean, or cost reduction, including seed cost.

Table 12. Critical maize density for intercrop soybean (CDm/s25) at different soybean densities (1.8, 3.0, 5.1, 8.5, 14.3, and 24.0 plants m^{-2}), mean of 1985 and 1986.

Soybean density	Cobb			Davis		
	Seed yield			Seed yield		
	Sole	25% sole	CDm/s25[a]	Sole	25% sole	CDm/s25
plants m^{-2}	g m^{-2}		plants m^{-2}	g m^{-2}		plants m^{-2}
1.8	142.1	35.5	4.57	97.7	24.5	1.75
3.0	157.3	39.3	6.76	127.8	31.9	2.80
5.1	198.6	49.6	7.67	180.7	45.2	3.42
8.5	274.4	68.6	10.78	238.9	59.7	4.15
14.3	299.6	74.9	11.49	265.3	66.3	2.83
24.0	356.4	89.1	11.50	292.1	73.0	3.81

[a]CDm/s25 is the density of maize (m), the dominant crop, below which the intercrop yield of soybean (s), the dominated crop, is equal or greater than 25% of its sole crop yield.

CHAPTER V
MAIZE/SOYBEAN INTERCROPPING AND PLANT DENSITY: OPTIMUM PLANT DENSITY, EVALUATED USING CONSTANT PLANT DENSITY AND TIME-WEIGHTED AVERAGE PLANT DENSITY CONCEPTS

Introduction

Intercropping, the growing of two or more crops simultaneously on the same field, may increase production in both time and space. Intercrop competition occurs during all or part of crop growth and farmers manage more than one crop at a time in the same field (Francis, 1985). From this definition, it appears that the time factor is as important as the space or land factor in assessing intercropping efficiency.

Yet, the analyses of intercrops have often not considered time. The relative yield total (RYT) of de Wit and ven den Bergh (1965) was used by Trenbath (1974) to compare biomass production of mixtures to monocultures of forage species. These forage crops were planted and harvested at the same points in time. Since crop duration was equal in the crop mixtures and the component sole crops, production per unit of time was not and need not be considered. Then IRRI (1974) advanced the concept of land equivalent ratio (LER). Mathematically, RYT is identical to LER if yield is expressed on a per-area basis rather than a per-plant basis. Land equivalent ratio, defined as the relative land area required as sole crops to produce the same yields as from the intercrops, has been the most generally used single index for

expressing the yield advantage of intercropping systems (Willey, 1979a). It has had widespread use in assessing biological efficiency of intercropping (IRRI, 1974; Trenbath, 1976; Beste, 1976; Cunard, 1976; Willey, 1979a; Mead and Willey, 1980; Ahmed and Rao, 1982; Beets, 1982; Allen and Obura, 1983; Hiebsch and McCollum, 1987). The reasons for the widespread adoption of the LER concept are 1) it provides a standardized basis so that crops can be "added" to obtain "combined yields," 2) comparison between individual LERs can indicate competitive effects, and 3) the total LER can be taken as a measure of the relative yield advantage (Mead and Willey, 1980).

Huxley and Maingu (1978) emphasized that all intercrop yields should be compared with the sole crop at its optimum population and spacing. The definition of LER requires that the solecrops used in the calculation be at their optimum densities. Trenbath (1974, 1976) has stated that to avoid an effect on LER due simply to plant density, the intercrop and the solecrops with which it is to be compared should be grown at the same "effective" density. This means that the density of the intercrop (DI) should equal 1.0 (DI = 1.0). The population of each solecrop is assigned a density of 1.0, and each intercrop component density is a fraction of its respective solecrop density, the sum of these fractional densities (FD) equalling 1.0. This concept of maintaining a constant plant density (CPD) in the solecrops and intercrop was developed with equal-time forage mixtures and has been proposed and partially adopted for unequal-time crop mixtures.

In intercropping where all component crops are not planted and harvested at the same points in time, plant density changes during the

course of the intercropping and is always less than the sum of the fractional densities when averaged over the duration of the intercropping; therefore the constant plant density concept does not satisfy the objectives intended and is not applicable (Hiebsch, 1980). For example, for a relay-intercrop with two 100-day crops overlapped by 20 days (total intercrop system duration of 180 days), it makes no logical sense to plant a FD = 0.5 of each of the component crops as called for by the CPD concept. It has been proposed that the appropriate intercrop density to use for comparisons with solecrops is a time-weighted average plant density (TWAPD) equal to 1.0 (Hiebsch, 1980). For the above relay-intercrop, planting each component crop at a FD = 0.9 satisfies the proposed TWAPD = 1.0 concept.

The objectives of this study were 1) to compare the CPD = 1.0 and TWAPD = 1.0 concepts to determine which density concept is the more appropriate for comparing intercrops and solecrops and 2) to determine whether the solecrop density and intercrop component density ratios affect the relative merits of the two density concepts.

Materials and Methods

Field experiments were conducted on the Agronomy Farm at the University of Florida, Gainesville, during the 1985 and 1986 growing seasons. The soil, a Lake fine sand (hyperthermic, coated Typic Quartzipsammenta), had a Melich I extractable test of 105 ppm of P, 60 ppm of K, 28 ppm of Mg, 300 ppm of Ca, and a pH of 6.2.

The experimental design and the cultural practices were as described in Chapter IV.

Determination of Relative Yield, Land and Area-Time-Equivalent Ratios

Constant and time-weighted average plant density concepts were compared. Relative yield of maize and soybean were calculated from seed and kernel yield data and used to determine land equivalent ratio and area-time equivalent ratio at both constant and time-weighted average plant densities (CPD and TWAPD) as a function of sole maize density. The data were expressed using two approaches 1) for different maize/soybean plant density ratios, and 2) for three intercrop maize plant densities (0.88, 1.58, and 3.15 plants m^{-2}); each approach with three intercrop soybean densities (3.0, 8.5, and 24.0 plants m^{-2}). The maize/soybean plant density ratios chosen for the CPD concept were 50/50, 25/75, and 12.5/87.5 and for the TWAPD, were 74/74, 53/89, and 34/102 for Cobb cv., 72/72, 53/88, and 34/102 for Davis cv. Land and area-time equivalent ratios were finally compared within and between the two concepts.

Terminology

The following terms were used in calculations for the relative yields and land and area-time equivalent ratios for the CPD and TWAPD comparisons.

DSM density of solecrop maize

DIM density of intercrop maize

DSS density of solecrop soybean

DIS density of intercrop soybean

CPD constant plant density (concept)

TWAPD time-weighted average plant density (concept)

FDm fractional density of maize in the intercrop

FDs fractional density of soybean in the intercrop

TD threshold density

RTm relative time (duration) of maize to the intercrop

RTs relative time (duration) of soybean to the intercrop

YSM yield of solecrop maize

YIM yield of intercrop maize

YSS yield of solecrop soybean

YIS yield of intercrop soybean

RYm relative yield of maize

RYs relative yield of soybean

LER land equivalent ratio

ATER area-time equivalent ratio

LER and ATER for Different Maize/Soybean Ratios (Approach 1)

The DSM selected were 1.58, 3.15, 6.3, and 12.6 plants m^{-2}, corresponding to 25, 50, 100, and 200% of 6.3 plants m^{-2} which was defined as the threshold maize density. The TD was the plant density corresponding to the inflection point (termination of linear increase) of the yield response curve to increasing plant density as determined by the linear-plateau regression model.

Constant plant density

The CPD is defined as FDm + FDs = 1.0 [1]. Maize/soybean (Fdm/Fds) ratios were chosen to satisfy equation [1]. For a given

DSM, DIS, and maize/soybean plant density ratio, the following variables were calculated and used to plot Figs. 27 and 28.

DSS = DIS/FDs

e.g., In a 25/75 ratio and DIS = 3.0 plants m^{-2},

DSS = 3.0/0.75 = 4.0 plants m^{-2}.

DIM = DSM x FDm

e.g., In a 25/75 ratio and DSM = 1.58 plants m^{-2},

DIM = 1.58 x 0.25 = 0.39 plant m^{-2}.

The 0.39 plant m^{-2} fell below the 15 intercrop maize density range (0.80 to 15.4 plants m^{-2}) tested, therefore was not considered. This was done for any calculated density which fell outside the range tested.

In a 50/50 ratio and DSM = 1.58 plants m^{-2}, DIM = 1.58 x 0.50 = 0.79 plant m^{-2}, close to 0.80 plant m^{-2}.

YSM = yield of solecrop maize at a given DSM.

Yield was sometimes obtained by interpolation, if the density was not exactly one of those tested, assuming a linear response between two consecutive densities. Interpolation was also used for intercrop maize, for sole and intercrop soybean yield.

YIM = yield of intercrop maize corresponding to a DIM and at a given DIS (3.0, 8.5, or 24.0 plants m^{-2}).

YSS = yield of sole crop soybean corresponding to a DSS.

YIS = yield of intercrop soybean at a given DIS and corresponding to a DIM calculated.

RYm = YIM/YSM

RYs = YIS/YSS

$$LER = RYm + RYs$$

$$ATER = (RYm \times RTm) + (RYs \times RTs), \text{ where}$$

$$RTm = \frac{\text{Duration of solecrop maize}}{\text{Duration of the intercrop system}}$$

$$RTs = \frac{\text{Duration of solecrop soybean}}{\text{Duration of the intercrop system}}$$

e.g., for the intercrop maize/Cobb where the duration (mean of 1985 and 1986) of the solecrop maize, the solecrop Cobb, and the intercrop is 116, 163, and 207, respectively, RTm = 116/207 = 0.56 and RTs = 163/207 = 0.79. For the intercrop maize/Davis where the duration of the solecrop Davis and the intercrop is 140 and 184, respectively, RTm = 116/184 = 0.63 and RTs = 0.76.

Time-weighted average plant density

The time-weighted average plant density is defined as

$$(FDm \times RTm) + (FDs \times RTs) = 1.0 \qquad [2].$$

For each maize/soybean (FDm/FDs) ratio, the FDm and FDs were calculated using equation [2].

For example, in a maize/Cobb intercrop with a FDm/FDs ratio of 50/50 or 1/1, FDm = FDs. Then (FDm x 0.56) + (FDs x 0.79) = 1.0, therefore FDm = FDs = 0.74, giving a FDm/FDs ratio of 74/74. Similarly, with a FDm/FDs ratio of 25/75 or 1/3, 3FDm = 1FDs, then (FDm x 0.56) + (3FDm x 0.79) = 1.0, therefore FDm = 0.34 and FDs = 1.02, giving a 34/102 ratio. A midpoint FDm/FDs ratio of 37.5/62.5 was selected and calculated to give a FDm = 0.53, FDs = 0.89, and a ratio of 53/89.

Maize/Davis intercrop ratios were similarly determined. Then, RYm, RYs, LER, and ATER were calculated using the same procedure as described in constant plant density.

LER and ATER for Constant Intercrop Maize and Soybean Densities (Approach 2)

The three constant DIM selected were 0.88 plant m^{-2} which was the lowest common intercrop maize density for the three intercrop soybean densities (3.0, 8.5, and 24.0 plants m^{-2}), then 1.58 and 3.15 plants m^{-2}. The DIM selected were maintained low (below or equal to 50% of the TD of 6.3 plants m^{-2}) to minimize the suppressive effect of maize on soybean.

Constant plant density

For a given DIM and DIS, LER and ATER were plotted in Figs. 29 and 30, from the lowest DSM possible to a DSM of 2TD (12.6 plants m^{-2}). The following calculations were made:

FDs = DIS/DSS

The lowest FDs was calculated by dividing DIS by the highest DSS (77.5 plants m^{-2}).

DSM = DIM/FDm

From a rearrangement of equation [1] (FDm = 1.0 - DIS/DSS), the lowest FDm = 1.0 - DIS/77.5.

For example, for DIM = 0.88 and DIS = 3.0 plants m^{-2} combination, the lowest FDs = 3.0/77.5 = 0.04 and the lowest FDm = 1.0 - 0.04 = 0.96. Therefore, DSM = 0.88/0.96 = 0.92 plant m^{-2}.

The other values of DSM corresponded to the values obtained in the TWAPD, plus the TD and the 2TD values. For each DSM, the FDs, DSS, and FDm were calculated. Then YSM, YIM, YSS, YIS, RYm, RYs, LER, and ATER were determined as previously described.

Time-weighted average plant density

The FDm and FDs were calculated from equation [2]. For the maize/Cobb intercrop, (FDm x 0.56) + (FDs x 0.79) = 1.0. By rearranging, FDm = 1.786 - 1.411 FDs and FDs = 1.255 - 0.71 FDm. For the maize/Davis intercrop, (FDm x 0.63) + (FDs x 0.76) = 1.0. By rearranging FDm = 1.587 - 1.206 FDs and FDs = 1.316 - 0.83 FDm.

The following conditions were assumed to be observed:

$$FDm \leq 1.0 \text{ and } FDs \leq 1.0$$

For example, for maize/Cobb at DIM = 0.88 and DIS = 3.0 plants m^{-2},

when FDm = 1.0 then FDs = 1.266 - 0.71 x 1.0 = 0.56

when FDs = 1.0 then FDm = 1.786 - 1.411 x 1.0 = 0.38.

Therefore,

$0.38 \leq FDm \leq 1.0$ and $0.56 \leq FDs \leq 1.0$ are the conditions to be observed.

When FDm = 1.0 then DSM = DIM/FDm = 0.88/1.0 = 0.88 plants m^{-2}.

When FDm = 0.38 then DSM = DIM/FDm = 0.88/0.38 = 2.32 plants m^{-2}.

At DIM = 0.88 plant m^{-2}, the range of DSM is therefore between 0.88 and 2.32 plants m^{-2}. The DSS is calculated from a given DIS and a calculated FDs. The range of DSM for maize/Davis is determined in a similar manner.

Results and Discussion

LER and ATER for Different Maize/Soybean Ratios (Approach 1)

Constant vs. time-weighted average plant density

Land and area-time equivalent ratios (LER and ATER) for TWAPD were greater than LER and ATER for CPD (Figs. 27 and 28). The differences were greater in maize/Cobb than in maize/Davis intercrops, and for maize/Cobb were more pronounced at the higher DIS (8.5 < 24.0 plants m^{-2}) than at the lower DIS (3.0 plants m^{-2}) (Table 13). For maize/Davis, LER and ATER were only slightly greater at TWAPD than CPD and seemed not to be affected by DIS. The TWAPD, which considers the duration of crop cycle in the determination of fractional density for intercropping, appeared to be more appropriate for the system and the environment used in this study. Only about 60% of the intercropping duration is used by the first crop, maize, which is harvested in July allowing enough time for even a third crop to be produced as its substitute in the system. It is suggested that in such situations, using the CPD concept will underestimate the plant density combination for intercropping. The advantage of maize/Cobb over maize/Davis is probably related to the longer duration of Cobb (163 days) compared to Davis (140 days). At maize maturity and harvest, Davis soybeans had already flowered and were not able to recover vegetatively from the maize suppression whereas Cobb remained vegetative for 30 to 45 days (Fig. 21, Chapter IV).

Fig. 27. Relative yield values of intercrop maize and soybean (cv. Cobb) as a function of solecrop maize density. Relative yields expressed as land equivalent ratio (LER) and area-time equivalent ratio (ATER) at a constant plant density (CPD) and a time-weighted average plant density (TWAPD) for different maize/soybean plant density ratios (50/50, 25/75, and 12.5/87.5 for CPD and 74/74, 53/89, and 34/102 for TWAPD) and at three intercrop soybean (IS) densities (3.0, 8.5, and 24.0 plants m^{-2}).

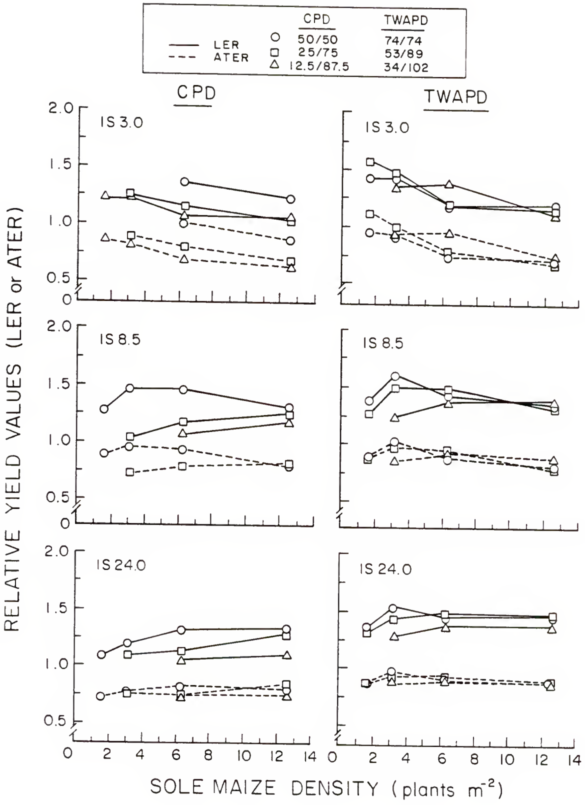
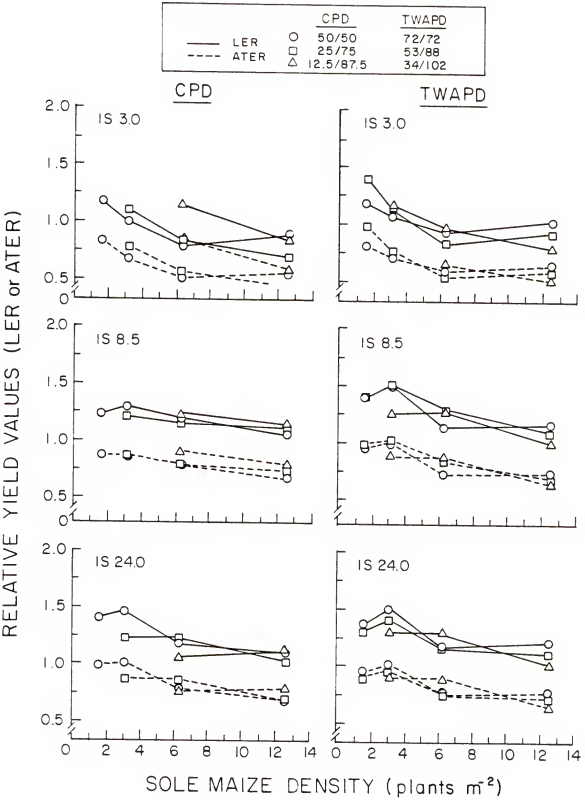

LER
ATER
CPD
TWAPD
50/50
25/75
12.5/87.5
74/74
53/89
34/102
CPD
TWAPD
IS 3.0
IS 8.5
IS 24.0
RELATIVE YIELD VALUES (LER or ATER)
SOLE MAIZE DENSITY (plants m-2)
0
0.5
1.0
1.5
2.0
2
4
6
8
10
12
14

Fig. 28. Relative yield values of intercrop maize and soybean (cv. Davis) as a function of solecrop maize density. Relative yields expressed as land equivalent ratio (LER) and area-time equivalent ratio (ATER) at a constant plant density (CPD) and a time-weighted average plant density (TWAPD) for different maize/soybean plant density ratios (50/50, 25/75, and 12.5/87.5 for CPD and 72/72, 53/88, and 34/102 for TWAPD) and at three intercrop soybean (IS) densities (3.0, 8.5, and 24.0 plants m^{-2}).



CPD
TWAPD
LER
ATER
50/50
25/75
12.5/87.5
72/72
53/88
34/102
CPD
TWAPD
IS 3.0
IS 8.5
IS 24.0
2.0
1.5
1.0
0.5
0
2
4
6
8
10
12
14
RELATIVE YIELD VALUES (LER or ATER)
SOLE MAIZE DENSITY (plants m⁻²)

Table 13. Land and area-time equivalent ratios for constant and time-weighted plant densities in maize intercropped with two soybean cultivars (Cobb and Davis) at three densities (3.0, 8.5, and 24.0 plants m^{-2}), averaged over different maize/soybean density ratios, mean of 1985 and 1986.

System	Intercrop soybean density (plants m^{-2})	Land equivalent ratio			Area-time equivalent ratio		
		Plant density concept			Plant density concept		
		Constant	Time-weighted	Diff.	Constant	Time-weighted	Diff.
Maize/Cobb							
	3.0	1.19	1.32	0.11	0.82	0.87	0.05
	8.5	1.22	1.39	0.17	0.83	0.90	0.07
	24.0	1.16	1.41	0.25	0.77	0.92	0.15
	Mean	1.19	1.37	0.18	0.81	0.90	0.09
Maize/Davis							
	3.0	0.97	1.04	0.07	0.67	0.69	0.02
	8.5	1.18	1.26	0.08	0.82	0.84	0.02
	24.0	1.20	1.25	0.05	0.83	0.83	0.00
	Mean	1.12	1.18	0.06	0.77	0.79	0.02

LER vs. ATER

For all densities of sole maize (DSM), ATER was less than LER, and generally less than 1.0 (Figs. 27 and 28, Table 13). By definition, ATER is the ratio of area-time required in solecropping to area-time used by the intercrop in producing the same quantities of all component crops (Hiebsch and McCollum, 1987). Based on this definition, we could postulate that LER indicates the land-use advantage for the season, but by ignoring the time factor it overestimates the biological efficiency which is a function of both land area and duration of the system.

Plant density effects on LER and ATER

As DSM increased, LER and ATER for both CPD and TWAPD decreased (Table 14). The decrease was greater for TWAPD than for CPD, and for maize/Davis than for maize/Cobb. As DSM increased, the density of intercrop maize (DIM) at any given maize/soybean ratio also increased, causing greater suppression of intercrop soybeans, a reduction in the relative yield of soybeans (RYs), and lower relative yield totals for the intercrop. This reduction was more pronounced at 8.5 plants m^{-2} and not so at higher DIS (24.0 plants m^{-2}), for Cobb. In general, the suppression of the relative yield of Davis was almost equally higher as maize density increased at all DIS.

LER and ATER for Constant Intercrop Maize and Soybean Densities (Approach 2)

The LER or ATER for TWAPD was greater than the LER or ATER for CPD (Figs. 29 and 30). This was more pronounced at the lower DIS for

Table 14. Land and area-time equivalent ratios (LER and ATER) for constant and time-weighted average plant density as affected by maize and soybean density, averaged over different maize/soybean ratios, mean of 1985 and 1986.

System	Intercrop soybean density plants m^{-2}	Land equivalent ratio			Area-time equivalent ratio		
		Sole maize density			Sole maize density		
		3.15	6.3	12.6	3.15	6.3	12.6
Maize/Cobb		Constant plant density					
	3.0	1.23	1.19	1.16 (- 5.7)	0.85	0.83	0.79 (- 7.1)
	8.5	1.25	1.23	1.19 (- 4.8)	0.84	0.83	0.80 (- 4.8)
	24.0	1.14	1.16	1.19 (+ 4.4)	0.76	0.77	0.78 (+ 2.6)
	Mean	1.21	1.19	1.18 (- 2.5)	0.82	0.81	0.79 (- 3.6)
		Time-weighted average plant density					
	3.0	1.42	1.26	1.16 (-18.3)	0.96	0.83	0.72 (-25.0)
	8.5	1.45	1.43	1.35 (- 6.9)	0.95	0.92	0.83 (-12.6)
	24.0	1.42	1.44	1.44 (+ 1.4)	0.94	0.93	0.90 (- 4.2)
	Mean	1.43	1.38	1.32 (- 7.7)	0.95	0.89	0.82 (-13.7)
Maize/Davis		Constant plant density					
	3.0	1.06	0.94	0.90 (-15.1)	0.73	0.65	0.61 (-16.4)
	8.5	1.25	1.20	1.13 (- 9.6)	0.87	0.83	0.77 (-11.5)
	24.0	1.35	1.17	1.09 (-19.2)	0.94	0.81	0.75 (-20.2)
	Mean	1.22	1.10	1.04 (-14.7)	0.85	0.76	0.71 (-16.5)
		Time-weighted average plant density					
	3.0	1.12	0.91	0.91 (-18.7)	0.77	0.60	0.58 (-24.7)
	8.5	1.40	1.22	1.08 (-22.8)	0.96	0.82	0.69 (-28.1)
	24.0	1.39	1.19	1.11 (-20.1)	0.95	0.79	0.70 (-26.3)
	Mean	1.30	1.11	1.03 (-20.8)	0.89	0.74	0.66 (-25.8)

The number in parentheses are the percent change of LER and ATER from 3.15 to 12.6 maize plants m^{-2} (- = % reduction and + = % increase).

Fig. 29. Relative yield values of intercrop maize and soybean (cv. Cobb) as a function of solecrop maize density. Relative yield is expressed as land equivalent ratio (LER) and area-time equivalent ratio (ATER) at a constant plant density (CDP) and a time-weighted average plant density (TWAPD) for three intercrop maize plant densities (DIM) (0.88, 1.58, and 3.15 plants m^{-2}), each at three intercrop soybean (IS) densities (3.0, 8.5, and 24.0 plants m^{-2}).

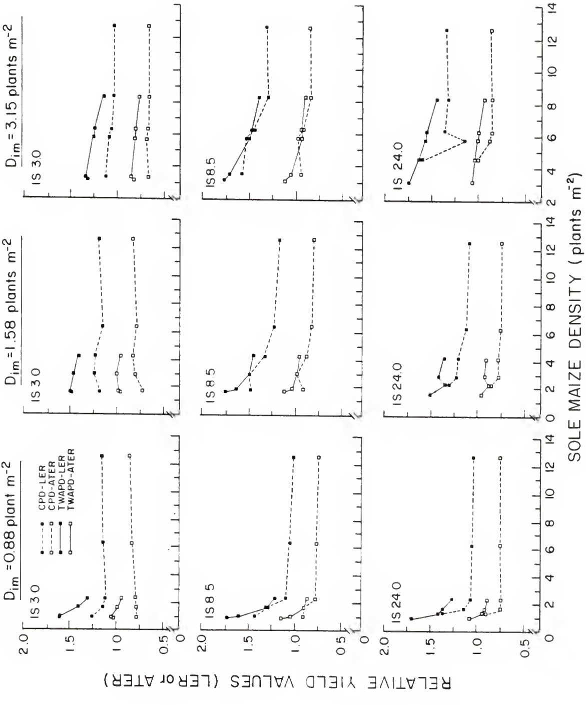
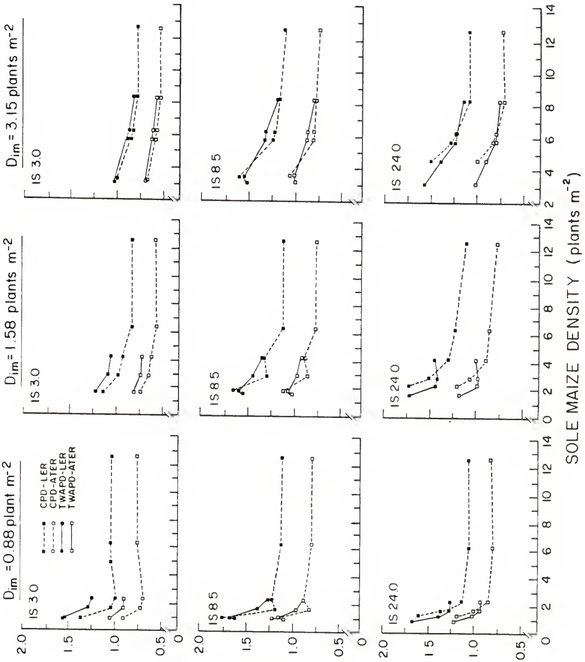

D_im =0.88 plant m^-2
D_im =1.58 plants m^-2
D_im = 3.15 plants m^-2
CPD-LER
CPD-ATER
TWAPD-LER
TWAPD-ATER
IS 3.0
IS 8.5
IS 24.0
RELATIVE YIELD VALUES (LER or ATER)
SOLE MAIZE DENSITY (plants m^-2)

Fig. 30. Relative yield values of intercrop maize and soybean (cv. Davis) as a function of solecrop maize density. Relative yield is expressed as land equivalent ratio (LER) and area-time equivalent ratio (ATER) at a constant plant density (CPD) and a time-weighted average plant density (TWAPD) for three intercrop maize plant densities (DIM) (0.88, 1.58, and 3.15 plants m^{-2}), each at three intercrop soybean (IS) densities (3.0, 8.5, and 24.0 plants m^{-2}).


D_{im} =0.88 plant m^{-2}
D_{im} = 1.58 plants m^{-2}
D_{im} = 3.15 plants m^{-2}
IS 3.0
IS 8.5
IS 24.0
CPD-LER
CPD-ATER
TWAPD-LER
TWAPD-ATER
RELATIVE YIELD VALUES (LER or ATER)
SOLE MAIZE DENSITY (plants m^{-2})

both Cobb and Davis. At the DIS of 8.5 and 24.0 plants m^{-2}, the TWAPD advantage over CPD was generally very slight but was still of practical consequence especially for Cobb, the late cultivar, which showed some regrowth potential during the 90 days growth period remaining after the maize removal. These results indicated that in a similar environment with a similar cropping pattern, the concept of CPD will likely underestimate the productivity of the intercrop.

CHAPTER VI
SUMMARY AND CONCLUSIONS

Intercropping is a stable and useful cropping practice for the tropics especially for those with small and scattered land holdings and limited inputs. The system is complex and many aspects of intercropping need more investigation. Plant density of intercrop components and suitable methods to assess density optima need greater resolution. Combinations of maize and legumes are common in intercropping practices. In these maize is generally the dominant or agressor component. To achieve successful production of the companion legume, e.g., soybean or the understory crop, we need quantification and better understanding of maize growth, development, canopy structure, light interception, and the dimensions of maize dominance in relation to the intercrop components density.

Field experiments were therefore conducted in 1985 and 1986 1) to assess the effects of a wide range of maize and soybean plant densities on canopy development, light interception, vegetative and reproductive growth, kernel and total dry matter (DM) yield of the maize component, and vegetative growth, seed and total DM yield of the soybean component, 2) to evaluate the concepts of determining optimum densities of intercrop components as a function of solecrop density by use of different efficiency indices.

Fifteen sole and intercrop maize hybrid (Pioneer Brand '3192') densities (0.8 to 15.4 plants m^{-2}), and 37 sole soybean densities

(1.76 to 77.5 plants m^{-2}) were planted in a systematic spacing "fan" design. Six intercrop soybean densities (1.8, 3.0, 5.1, 8.5, 14.3, and 24.0 plants m^{-2}) were planted each at a constant rate across the 15 maize densities. Two soybean cultivars, Cobb, maturity group (MG) VIII, and Davis (MG VI) were used. Three sole maize densities (1.9, 3.5, and 6.3 plants m^{-2}) and the 24.0 plants m^{-2} of sole crop soybean and intercrop soybean corresponding to the 1.9, 3.5, and 6.3 maize densities were sampled biweekly for growth analysis.

The following observations were recorded for maize: percent light interception (PLI); vertical leaf area distribution; leaf area index (LAI); DM accumulation (leaf, stem, stalk, ear, total); crop growth rate (CGR); plant height; tiller number per plant; yield components (ear number per plant, kernel-row number per ear, kernel number per row, per ear, per plant, and per unit area, weight per kernel); kernel, ear, stalk, and total DM yield per plant and per unit area; assimilate distribution (plant-ear ratio, ear priority, yield component vulnerability, yield adjustment, shelling percentage, and harvest index). For soybean the following measurements were recorded: LAI, DM accumulation, CGR, seed and total DM yield. For maize and soybean combined the following indices were determined: relative yields of intercrops, land equivalent ratio (LER), and area-time equivalent ratio (ATER). These were then used to compare constant plant density (CPD) and time-weighted average plant density (TWAPD) concepts.

There was no year x treatment interaction in all sets of data recorded, so the data for the 2 years were merged. Light interception

measurements at different morning times were similar for each maize density indicating that light interception can be measured at any time of the day.

Light distribution in maize canopy was highly concentrated at ear level. Approximately 40, 30, and 2% of light was intercepted below tassels and flag leaves (10 to 20 cm canopy depth) at 6.3, 3.5, and 1.9 maize plants m^{-2}, respectively. Maize plant density influenced canopy light interception significantly. At 35 DAP, total canopy light interception was already 40, 60, and 75% for 1.9, 3.5, and 6.3 plants m^{-2}, respectively. The 6.3 plant density significantly influenced the leaf area distribution, resulting in a greater proportion of the total leaf area to be at ear level, compared to the 1.9 and 3.5. Leaf area index increased significantly with increasing plant density. Critical LAI was not reached by the 1.9 plant density, but was achieved for the 3.5 and 6.3 plant densities. Dry matter accumulation and CGR were significantly influenced by plant density. Leaf, stem, and stalk dry weight did not differ significantly among the three densities until after 49 DAP indicating the onset of interplant competition. Plant height increased parabolically with increasing plant density.

The number of tillers per plant decreased linearly as density increased up to 3.5 plants m^{-2}, the cutoff point for tillering.

Ear number per plant (ENP) varied significantly with plant density (0.8 to 15.4 plants m^{-2}) from 1 to 3 ears in 1985 and 1 to 2 ears in 1986. All plants maintained at least one ear over the 15-density range. The cutoff points for 2-eared plants and 3-eared

plants were at 3.5 and 2.3 plants m^{-2}, respectively. Kernel-row number per ear (KRNE), kernel number per row (KNR), per ear (KNE), per plant, and per unit area were generally significantly influenced by plant density and differed among ears (ear 1 > ear 2 > ear 3). Weight per kernel (WK) per ear was not affected by plant density on ear 1 and on ear 2 until about the cutoff point (3.5 plants m^{-2}). On the average, weight per kernel per plant was not affected by plant density. The constancy of WK over a large range of densities indicates the small effect of this component in yield adjustment in maize. Yield components vulnerability (changeable) due to plant density was as follows: ENP > KNE > KNR > KRNE > WK, suggesting that as the density pressure is gradually removed, yield adjustment is first by changes in ENP followed by KNE, KNR, KRNE, and WK.

Kernel, stalk, and total DM yield per plant decreased reciprocally with increasing plant density. Kernel yield per unit area increased parabolically with increasing plant density, up to a maximum of 1080 g m^{-2} at about 10.0 plants m^{-2}, whereas stalk and total DM increased asymptotically. The percentage of total plant DM in the ear increased from about 20 to 70% from 65 to 105 DAP for the 1.9 and 3.5 plant densities, respectively, compared to about 14 to 62% for the 6.3 density for the same period, indicating a lower partitioning coefficient in the high density (6.3 plants m^{-2}). Shelling percentage was constant over the plant density range, whereas harvest index (partitioning coefficient) decreased slightly but not significantly with increasing plant density.

In general, maize yield was not significantly affected by the intercrop soybean possibly because the intercrop was planted later. Leaf area index and CGR of both soybean cultivars (Cobb and Davis) were significantly reduced by both intercropping and maize density. The intercropping effect was more pronounced on Davis, the early soybean cultivar (MG VI) than on Cobb (MG VIII), the late cultivar, which demonstrated some recovery potential and regrowth after the maize was harvested and removed. Maximum LAI for sole crop Cobb was 9.97 compared to 7.84 for Davis, whereas intercrop LAI maxima were 6.33, 3.67, and 0.88 for Cobb compared to 4.35, 2.11, and 0.81 for Davis, corresponding 1.9, 3.5, and 6.3 maize plant densities. Dry matter accumulation in both cultivars followed almost the same pattern as for LAI.

Solecrop soybean seed yield per unit area increased parabolically up to a maximum of about 545 g m^{-2} at 46.2 plants m^{-2} for Cobb, and about 320 g m^{-2} at 41.5 plants m^{-2} for Davis. Total DM per unit area increased asymptotically whereas seed and total DM per plant decreased reciprocally with increasing soybean plant density. Intercrop soybean seed and total DM yield per unit area and per plant for both cultivars decreased in a reciprocal relationship with increasing maize density. The highest intercrop soybean seed and total DM yields per unit area were obtained from the highest soybean plant density (24.0 plants m^{-2}). But, per plant, the highest seed and total DM yields were obtained from the lowest soybean plant density (1.8 plants m^{-2}). There were no significant cultivar x intercrop soybean density and maize density x intercrop soybean density interactions. The "critical

maize density" for intercrop soybean was lower (2 to 4 plants m^{-2}) for Davis than for Cobb (5 to 11 plants m^{-2}) and was positively related to the intercrop soybean density.

Land equivalent ratio and ATER for TWAPD were generally greater than LER and ATER for CPD. ATER was less than LER and less than 1.0.

Conclusions from these results are as follows:

Light interception can be measured at any time of a clear day.

Interplanting soybean at 35 days after maize planting drastically reduced the amount of light available to soybean to less than 60%.

Tassels and flag leaves may extinguish up to or more than 20% of incident irradiance, depending on maize plant density.

Ear proliferation depends on the environment and plant density.

Ear number per plant, kernel number per ear, and per row are the most important yield components for yield adjustment to change in plant density and probably should receive more consideration in the breeding program.

The cv. 3192 maize hybrid is highly allometric.

A late cultivar such as Cobb (MG VIII) appears to be better adapted and more productive in intercropping systems, such as the one used in this study.

Increasing the density of the suppressed intercrop component causes total yield per unit area to increase, but yield of individual plants decreased.

The plant density combination for intercrop components depends on the farmers goals and resources, but there is a "critical maize

density" for soybean survival and as well as one allowing acceptable soybean yield.

These data suggest that the merits of LER and CPD compared to ATER and TWAPD depend on the cropping system and the environment. By generalizing their use, LER occasionally overestimated the biological efficiency whereas CPD underestimated the plant density combination and the productivity of intercropping.

APPENDIX

Table 15. Level of significance (PR > F) comparing the distribution priority in yield (KY) and yield components between ear 1, ear 2, and ear 3 at different maize densities according to covariance analysis, mean of 1985 and 1986.

Maize density	Ear 1 vs. Ear 2 (Ear 1 > Ear 2)				
	KY*	KNE	KNR	KRNE	WK
m^{-2}	PR > F				
0.8	0.0001	0.0001	0.0001	0.705	0.140
1.0	0.0001	0.0001	0.0001	0.880	0.857
1.2	0.0001	0.0001	0.0001	0.410	0.181
1.5	0.0001	0.0001	0.0001	0.078	0.441
1.9	0.0001	0.0001	0.0001	0.003	0.300
2.3	0.0001	0.0001	0.0001	0.0001	0.134
2.8	0.0001	0.0001	0.0001	0.0001	0.721
3.5	0.0001	0.0001	0.0001	0.0001	0.086

*KY = kernel yield

KNE = kernel number per ear

KNR = kernel number per row

KRNE = kernel-row number per ear

WK = weight per kernel

Ear 1 vs. Ear 3		(Ear 2 > Ear 3)			Ear 2 vs. Ear 3		(Ear 2 > Ear 3)		
KY	KNE	KNR	KRNE	KW	KY	KNE	KNR	KRNE	KW
PR > F									
0.0001	0.0001	0.0001	0.0001	0.040	0.0001	0.0001	0.0001	0.0001	0.013
0.0001	0.0001	0.0001	0.0001	0.009	0.0001	0.0001	0.0001	0.0001	0.016
0.0001	0.0001	0.0001	0.0001	0.003	0.0001	0.0001	0.0001	0.0001	0.007
0.0001	0.0001	0.0001	0.0001	0.004	0.0001	0.0001	0.0001	0.0001	0.004
0.0001	0.0001	0.0001	0.0001	0.002	0.0001	0.0001	0.0001	0.0001	0.006
0.0001	0.0001	0.0001	0.0001	0.009	0.0001	0.0001	0.0001	0.0001	0.009
–	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–	–

Table 16. Kernel yield per plant and per unit area of intercrop maize (IM) with three soybean densities (1.8, 5.1, and 14.3 plants m^{-2}), as affected by maize plant density in 1985.

Maize density	Kernel yield					
	IM (IS 1.8)		IM (IS 5.1)		IM (IS 14.3)	
m^{-2}	g m^{-2}	g $plant^{-1}$	g m^{-2}	g $plant^{-1}$	g m^{-2}	g $plant^{-1}$
0.8	247.2	309.0	269.0	336.2	311.3	389.1
1.0	309.0	312.2	342.0	345.5	393.6	397.5
1.2	389.0	316.3	420.0	341.4	475.1	386.3
1.5	466.6	307.0	483.6	318.2	494.3	325.2
1.9	534.5	285.8	530.6	283.8	586.4	313.6
2.3	619.6	268.2	658.1	284.9	738.1	319.5
2.8	612.8	215.0	749.9	263.1	783.6	274.9
3.5	706.9	200.8	790.4	224.5	916.6	260.4
4.3	855.5	196.6	826.2	189.9	928.6	213.5
5.4	873.5	162.7	912.2	169.9	1025.3	190.0
6.3	932.2	147.3	952.9	150.5	1101.8	174.1
8.2	1066.4	130.4	1083.8	132.5	1218.8	149.0
10.2	1080.7	106.4	1096.9	108.0	1225.3	120.6
12.5	1093.3	87.5	1088.7	87.1	1202.5	96.2
15.4	1094.5	71.2	1093.5	71.1	1225.3	79.7

Table 17. Total dry matter yield per plant and per unit area of intercrop maize (IM) with three soybean densities (1.8, 5.1, and 14.3 plants m^{-2}), as affected by maize plant density in 1985.

Maize density	Total dry matter					
	IM (IS 1.8)		IM (IS 5.1)		IM (IS 14.3)	
m^{-2}	$g\ m^{-2}$	$g\ plant^{-1}$	$g\ m^{-2}$	$g\ plant^{-1}$	$g\ m^{-2}$	$g\ plant^{-1}$
0.8	484.9	606.1	527.6	659.6	566.9	708.6
1.0	596.0	602.0	690.7	697.6	714.8	722.1
1.2	737.0	599.2	846.8	688.4	844.1	686.3
1.5	913.6	601.0	968.4	637.1	903.2	594.2
1.9	1044.4	558.5	1091.9	583.9	1023.0	547.1
2.3	1206.0	522.1	1352.8	585.6	1328.7	575.2
2.8	1282.2	449.9	1546.9	542.8	1373.8	482.0
3.5	1508.0	428.4	1740.4	494.4	1631.1	463.4
4.3	1815.0	417.2	1796.7	413.0	1753.5	403.1
5.4	1916.7	356.9	2045.4	380.9	1992.5	371.0
6.3	2087.0	329.7	2137.5	337.7	2093.7	330.7
8.2	2390.7	292.2	2186.9	267.3	2110.1	258.0
10.2	2494.1	245.5	2101.7	236.4	2466.1	242.7
12.5	2546.9	203.7	2521.1	201.7	2321.1	185.7
15.4	2667.6	173.4	2704.0	175.8	2348.3	152.7

Table 18. Level of significance comparing kernel yield between seven maize cropping patterns (one sole and six intercrop at six soybean densities), according to t-test.

Cropping patterns	Kernel yield	PROB > ITI Ho: LS MEAN (I) = LS MEAN (J)						
		I/J						
	g m^{-2}	SM	IM 1.8	IM 3.0	IM 5.1	IM 8.5	IM 14.3	IM 24.0
					1985			
SM	790.4	-	0.80	0.69	0.49	0.18	0.18	0.20
IM 1.8	799.9	0.80	-	0.88	0.66	0.27	0.28	0.30
IM 3.0	805.6	0.69	0.88	-	0.77	0.335	0.35	0.38
IM 5.1	816.9	0.49	0.66	0.77	-	0.52	0.52	0.56
IM 8.5	841.7	0.18	0.27	0.35	0.52	-	0.99	0.95
IM 14.3	841.8	0.18	0.27	0.35	0.52	0.99	-	0.95
IM 24.0	839.4	0.20	0.30	0.38	0.55	0.95	0.95	-
					1986			
SM	678.6	-		0.33		0.30		0.70
IM 3.0	650.9	0.33		-		0.96		0.18
IM 14.3	649.4	0.30		0.95		-		0.16
IM 24.0	689.5	0.70		0.18		0.16		-

Table 19. Predictive equations from regression analysis relating kernel and total dry matter (DM) per plant and per unit area of intercrop maize at three soybean densities (1.8, 5.1, and 14.3 plants m^{-2}) with maize density in 1985.

Soybean density	Equations	R^2	P > F
plants m^{-2}	Kernel yield (g m^{-2})		
1.8	$y = 229.1\ Xm - 10.83\ Xm^2$	0.98	0.0001
5.1	$y = 241.0\ Xm - 11.72\ Xm^2$	0.97	0.0001
14.3	$y = 270.5\ Xm - 13.17\ Xm^2$	0.97	0.0001
	Kernel yield (g $plant^{-1}$)		
1.8	$y^{-1} = 0.0023 + 0.00075\ Xm$	0.96	0.0001
5.1	$y^{-1} = 0.0020 + 0.00076\ Xm$	0.98	0.0001
14.3	$y^{-1} = 0.0017 + 0.00068\ Xm$	0.96	0.0001
	Total DM (g m^{-2})		
1.8	$y = 2700.8\ (1 - e^{-0.246\ Xm})$		
5.1	$y = 2560.9\ (1 - e^{-0.304\ Xm})$		
14.3	$y = 2391.2\ (1 - e^{-0.323\ Xm})$		
	Total DM (g $plant^{-1}$)		
1.8	$y^{-1} = 0.0013 + 0.00028\ Xm$	0.96	0.0001
5.1	$y^{-1} = 0.0011 + 0.00031\ Xm$	0.99	0.0001
14.3	$y^{-1} = 0.0010 + 0.00035\ Xm$	0.93	0.0001

Table 20. Leaf area index (LAI) and dry matter (DM) accummulation of two intercrop soybean (IS) cultivars (Cobb and Davis) at three maize densities (1.9, 3.5, and 6.3 plants m^{-2}) as compared to sole soybean (SS), mean of 1985 and 1986.

Cropping patterns/ Maize density	Days after planting							
	14		28		42		56	
	Cobb	Davis	Cobb	Davis	Cobb	Davis	Cobb	Davis
				LAI				
SS	0.10 aA*	0.09 aA	0.71 aA	0.60 aB	1.94 aA	2.16 aA	3.81 aA	5.22 aA
IS/1.9	0.09 aA	0.09 aA	0.40 bA	0.44 bA	1.12 bA	1.03 bA	1.54 A	1.65 bA
IS/3.5	0.10 aA	0.10 aB	0.28bcB	0.34bcB	0.65 cA	0.66 cA	1.04 bA	1.05 bA
IS/6.3	0.08 aA	0.09 aA	0.23 cA	0.22 cA	0.36 cA	0.56 cA	0.44 bA	0.43 bA
LSD (0.05)	0.024	0.03	0.15	0.12	0.35	0.34	1.64	2.37
				DM				
				g				
SS	0.27 aA	0.25 aA	2.22 aA	2.08 aA	5.61 aB	6.95 aA	15.14 aA	17.82 aA
IS/1.9	0.20 bA	0.21abA	0.99 bA	1.11 bA	2.79 bA	2.40 bA	4.66 bA	4.87 bA
IS/3.5	0.17 bA	0.20abA	0.52bcB	0.65bcA	1.27 cA	1.17 cA	2.60bcA	1.76 bA
IS/6.3	0.12 cB	0.18 bA	0.31 cA	0.32 cA	0.47 cA	0.86 cA	0.90 cA	1.03 bA
LSD (0.05)	0.03	0.05	0.51	0.50	1.42	1.15	2.29	8.04

*Means followed by the same lower case letters in the column and by the same upper case letters in the row within the same day are not significantly different at 5% level of probability according to DMRT.

Days after planting							
70		84		98		112	
Cobb	Davis	Cobb	Davis	Cobb	Davis	Cobb	Davis
				LAI			
7.33 aA	7.40 aA	9.05 aA	7.35 aA	9.97 aA	7.84 aA	6.61 aA	4.88 aA
3.14 bA	3.55 bA	5.46 bA	3.66 bA	6.33 bA	4.35 bB	4.74 bA	2.70 bB
1.74 cA	1.76 cA	1.84 cA	1.15 cB	3.67 cA	2.11 cB	1.87 cA	1.22 bcA
0.52 dB	0.83 cA	0.45 dA	0.57 cA	0.86 dA	0.81 dA	0.88 cA	0.34 cA
0.43	1.44	0.92	1.54	0.55	1.03	1.15	1.66
				DM			
				g			
30.80 aA	31.43 aA	44.64 aA	36.30 aA	51.20 aA	44.18 aA	48.78 aA	39.77 aA
10.59 bA	11.22 bA	20.71 bA	16.22 bA	27.11 bA	22,90 bA	34.64 bA	23.70 bB
4.52 cA	5.16bcA	5.98 cA	4.50 cA	13.31 cA	10.25 cA	10.56 cA	9.38 cA
1.15 cA	1.83 cA	1.75 cA	2.15 c A	2.80 dA	3.93 dA	5.2 cA	2.79 c A
4.30	6.06	7.42	7.23	2.47	4.40	9.23	12.83

Table 21. Influence of plant density on seed yield (SY) and total dry matter (TDM) per plant and per unit area in two sole soybean cultivars (Cobb and Davis), mean of 1985 and 1986.

Plant density	SY				TDM			
	Cobb		Davis		Cobb		Davis	
m^{-2}	g $plant^{-1}$	g m^{-2}	g $plant^{-1}$	g m^{-2}	g $plant^{-1}$	g m^{-2}	g $plant^{-1}$	g m^{-2}
1.8	80.7	142.1	55.6	97.9	177.9	313.2	118.4	208.5
1.9	69.6	136.1	48.6	95.1	161.9	316.6	103.7	202.8
2.2	59.9	130.2	53.4	116.2	137.1	298.2	110.1	239.5
2.4	61.7	149.3	47.1	113.8	135.9	328.7	99.6	240.8
2.7	59.1	158.7	50.0	134.2	133.4	357.9	103.5	277.8
3.0	52.8	157.3	42.9	127.8	122.1	364.0	89.6	267.1
3.3	47.2	156.3	42.6	141.0	123.6	409.4	78.2	325.2
3.7	47.7	175.7	40.2	147.9	117.3	431.6	86.2	317.4
4.1	47.6	194.9	41.9	171.3	101.9	416.6	89.0	363.8
4.5	45.5	206.7	43.4	197.3	104.5	474.4	98.4	447.0
5.0	39.3	198.6	35.7	180.7	93.2	471.3	74.9	378.8
5.6	40.9	230.5	32.1	181.0	99.6	561.9	67.7	381.7
6.2	37.9	236.9	29.2	182.3	92.4	577.1	63.2	393.5
6.9	32.9	227.5	32.2	223.1	73.9	511.6	66.4	459.1
7.7	31.7	244.4	28.6	221.0	75.0	578.5	62.4	480.0
8.5	32.1	274.4	28.0	238.9	74.4	634.9	62.9	537.2
9.5	31.1	295.5	24.5	233.0	70.1	665.8	56.6	537.3
10.5	27.0	284.3	25.4	267.2	64.2	676.5	54.9	578.6
11.7	26.9	315.5	24.3	285.7	63.7	748.0	52.1	612.0
13.0	25.9	337.2	17.6	229.7	56.5	736.4	39.4	513.7
14.5	20.7	299.6	18.3	265.3	48.5	701.8	39.2	567.3

Table 21--continued

Plant density	SY				TDM			
	Cobb		Davis		Cobb		Davis	
m^{-2}	g $plant^{-1}$	g m^{-2}	g $plant^{-1}$	g m^{-2}	g $plant^{-1}$	g m^{-2}	g $plant^{-1}$	g m^{-2}
16.1	18.6	299.1	18.4	295.1	45.7	733.5	40.7	653.2
17.8	17.1	304.4	18.9	337.1	40.1	715.0	43.3	771.4
19.9	14.2	283.3	15.0	298.2	35.2	700.1	31.6	627.9
22.0	14.7	323.8	15.4	340.3	37.6	827.4	34.1	751.2
24.5	14.5	356.4	11.9	292.1	35.7	875.2	28.8	705.7
27.2	13.9	378.0	13.4	366.6	33.2	903.5	29.9	813.8
30.2	13.6	412.8	10.9	328.5	32.7	988.1	26.2	790.5
33.7	12.7	429.5	10.3	348.1	29.2	985.4	25.3	853.5
37.5	12.1	455.8	9.7	363.7	27.0	1011.5	24.2	908.5
41.5	11.2	465.3	9.4	390.9	27.9	1157.2	22.3	925.4
46.2	11.8	547.3	7.2	333.4	28.2	1304.7	16.4	757.4
51.3	10.6	545.1	6.2	320.6	24.8	1274.2	16.1	625.1
57.2	8.9	507.9	5.0	288.5	19.9	1137.5	11.9	679.6
63.5	7.2	455.0	4.6	296.3	19.9	1261.8	11.3	716.9
70.8	6.2	439.7	3.7	262.7	16.7	1180.5	10.5	743.7
77.5	5.7	442.2	3.1	238.8	14.2	1100.6	8.7	674.6

Table 22. Seed and total dry matter (TDM) yield per plant and per unit area of two intercrop soybean cultivars (Cobb and Davis) at 1.8 plants m^{-2}, as affected by maize plant density in 1985.

Maize density	SY				TDM*			
	Cobb		Davis		Cobb		Davis	
m^{-2}	g $plant^{-1}$	g m^{-2}	g $plant^{-1}$	g m^{-2}	g $plant^{-1}$	g m^{-2}	g $plant^{-1}$	g m^{-2}
0.72	77.9	140.2	69.2	124.6	148.5	267.4	129.7	233.4
0.78	84.7	152.4	42.7	76.8	166.3	299.4	81.7	147.0
0.86	84.0	151.2	49.5	89.2	162.3	292.2	93.5	168.4
0.96	78.5	141.4	34.4	62.0	147.3	265.2	64.4	116.0
1.08	77.9	140.2	36.4	65.6	150.0	270.0	69.7	125.4
1.24	80.5	145.0	24.2	44.0	152.0	273.6	49.9	89.9
1.45	61.4	110.6	21.7	39.0	113.0	203.4	43.4	78.2
1.75	54.5	98.2	13.7	24.6	96.8	174.2	28.1	50.6
2.20	42.3	76.2	6.0	10.8	76.0	136.8	15.0	27.0
2.97	40.0	72.0	8.9	16.0	71.0	127.8	19.8	35.6
4.57	23.0	41.4	3.0	5.4	39.5	71.2	7.7	13.8
9.87	13.7	24.6	1.3	2.4	21.8	39.2	2.7	4.8

*TDM at maturity included only seed and stems.

Table 23. Seed and total dry matter (TDM) yield per plant and per unit area of two intercrop soybean cultivars (Cobb and Davis) at 5.1 plants m^{-2}, as affected by maize plant density in 1985.

Maize density	SY				TDM*			
	Cobb		Davis		Cobb		Davis	
m^{-2}	g $plant^{-1}$	g m^{-2}	g $plant^{-1}$	g m^{-2}	g $plant^{-1}$	g m^{-2}	g $plant^{-1}$	g m^{-2}
0.77	37.2	189.5	33.3	169.7	83.3	425.0	63.9	326.1
0.83	28.0	143.1	29.5	150.4	63.3	322.7	58.8	299.8
0.89	27.5	140.2	29.0	147.9	60.3	307.7	58.6	298.9
0.96	24.7	125.8	25.2	128.3	55.8	284.5	49.0	250.2
1.04	24.7	124.8	25.5	130.0	53.8	274.5	51.2	261.2
1.14	27.4	140.0	26.4	134.9	58.3	297.5	51.9	264.6
1.26	27.0	138.0	22.1	112.8	59.5	303.4	41.8	213.1
1.41	24.6	125.5	24.3	123.8	64.0	326.7	47.4	242.0
1.60	24.5	124.9	20.3	103.7	56.4	287.9	41.3	210.8
1.85	24.4	124.4	18.4	93.8	54.7	279.1	35.4	180.5
2.18	26.3	134.0	18.0	91.8	56.2	286.4	35.3	180.2
2.66	24.2	123.2	12.5	63.7	49.5	252.7	22.8	116.2
3.42	19.4	99.0	9.8	50.1	40.0	204.3	21.4	109.1
4.78	12.0	61.2	4.6	23.5	22.2	113.0	10.2	51.8
7.97	9.8	50.1	1.2	5.9	18.1	92.4	3.5	18.1

Table 24. Seed and total dry matter (TDM) yield per plant and per unit area of two intercrop soybean cultivars (Cobb and Davis) at 14.3 plants m^{-2}, as affected by maize plant density in 1985.

Maize density	SY				TDM*			
	Cobb		Davis		Cobb		Davis	
m^{-2}	g $plant^{-1}$	g m^{-2}	g $plant^{-1}$	g m^{-2}	g $plant^{-1}$	g m^{-2}	g $plant^{-1}$	g m^{-2}
0.80	17.5	250.5	21.5	306.9	42.3	604.8	40.2	575.4
0.87	16.3	233.6	19.5	278.8	39.8	569.3	38.1	545.2
0.94	15.7	224.6	19.6	280.4	40.5	578.6	37.6	537.8
1.03	18.6	226.1	13.8	197.8	44.6	637.4	26.7	381.3
1.13	12.0	172.1	15.0	214.0	27.5	292.8	31.0	444.1
1.26	13.0	186.2	16.2	232.5	30.0	429.8	32.0	457.3
1.41	11.6	166.0	14.9	213.7	24.3	347.2	29.0	415.0
1.62	13.5	192.5	10.5	149.6	30.4	434.8	26.4	377.1
1.89	12.8	183.5	11.2	160.2	28.0	401.2	23.4	334.2
2.26	11.7	166.8	8.4	120.0	25.9	371.0	16.4	234.1
2.83	11.3	162.1	3.7	52.7	24.5	349.8	8.0	115.2
3.78	11.1	158.3	2.0	28.1	22.0	315.4	4.7	67.3
5.68	8.8	125.5	1.3	18.5	16.7	238.3	3.3	47.1
11.49	7.4	106.2	0.0	0.0	13.7	196.5	0.0	0.0

Table 25. Level of significance comparing seed yield of six soybean densities in two cultivars (Cobb and Davis) intercropped with maize in 1985 and 1986.

1985								
Cultivar	Soybean density	Seed Yield	PROB > T Ho: LSMEAN (I) = LSMEAN (J) I/J					
	m^{-2}	$g\ m^{-2}$	1.8	3.0	5.1	8.5	14.3	24.0
Cobb	1.8	106.9	–	0.36	0.37	0.0001	0.0001	0.0001
	3.0	119.7	0.36	–	0.98	0.0001	0.0001	0.0001
	5.1	119.5	0.37	0.98	–	0.0001	0.0001	0.0001
	8.5	182.4	0.0001	0.0001	0.0001	–	0.66	0.0001
	14.3	188.2	0.0001	0.0001	0.0001	0.66	–	0.0001
	24.0	264.3	0.0001	0.0001	0.0001	0.0001	0.0001	–
Davis	1.8	45.4	–	0.34	0.0002	0.0001	0.0001	0.0001
	3.0	58.2	0.34	–	0.003	0.0001	0.0001	0.0001
	5.1	96.6	0.0002	0.003	–	0.02	0.0001	0.0001
	8.5	127.0	0.0001	0.0001	0.02	–	0.003	0.002
	14.3	165.5	0.0001	0.0001	0.0001	0.003	–	0.96
	24.0	166.1	0.0001	0.0001	0.0001	0.0002	0.96	–
					1986			
Cobb	3.0	103.6		–		0.0001		0.0001
	8.5	158.1		0.0001		–		0.0001
	24.0	197.0		0.0001		0.0001		–
Davis	3.0	51.7		–		0.0001		0.0001
	8.5	127.2		0.0001		–		0.0001
	24.0	198.3		0.0001		0.0001		–

Table 26. Predictive equations from regression analysis relating seed yield per plant and per unit area of two intercrop soybean cultivars (Cobb and Davis) at three densities (1.8, 5.1, and 14.3 plants m^{-2}) with maize density (Xm), mean of 1985 and 1986.

Soybean density	Soybean cultivar	Equations	R^2	P > F
plants m^{-2}		Seed yield (g m^{-2})		
1.8	Cobb	$y^{-1} = 0.0039 + 0.0042$ Xm	0.76	0.0001
	Davis	$y^{-1} = 0.0396 + 0.0543$ Xm	0.76	0.0001
5.1	Cobb	$y^{-1} = 0.0001 + 0.0052$ Xm	0.34	0.0001
	Davis	$y^{-1} = -0.0246 + 0.0230$ Xm	0.71	0.0001
14.3	Cobb	$y^{-1} = 0.0048 + 0.0006$ Xm	0.36	0.0001
	Davis	$y^{-1} = 0.0144 + 0.0154$ Xm	0.60	0.0001
		Seed yield (g $plant^{-1}$)		
1.8	Cobb	$y^{-1} = 0.0070 + 0.0075$ Xm	0.76	0.0001
	Davis	$y^{-1} = -0.0714 + 0.0978$ Xm	0.76	0.0001
5.1	Cobb	$y^{-1} = 0.0005 + 0.0263$ Xm	0.34	0.0001
	Davis	$y^{-1} = -0.125 + 0.1170$ Xm	0.71	0.0001
14.3	Cobb	$y^{-1} = 0.0681 + 0.0088$ Xm	0.36	0.0001
	Davis	$y^{-1} = -0.206 + 0.220$ Xm	0.60	0.0001

Table 27. Predictive equations from regression analysis relating total dry matter (DM) yield per plant and per unit area of two intercrop soybean cultivars (Cobb and Davis) at three densities (1.8, 5.1, 14.3 plants m^{-2}) with maize density (Xm), mean of 1984 and 1986.

Soybean density	Soybean cultivar	Equations	R^2	P > F
plants m^{-2}		Total DM ($g\ m^{-2}$)		
1.8	Cobb	$y^{-1} = 0.0016 + 0.0026\ Xm$	0.80	0.0001
	Davis	$y^{-1} = -0.0160 + 0.0228\ Xm$	0.90	0.0001
5.1	Cobb	$y^{-1} = -0.0009 + 0.0029\ Xm$	0.36	0.0001
	Davis	$y^{-1} = -0.0072 + 0.0082\ Xm$	0.66	0.0001
14.3	Cobb	$y^{-1} = 0.0019 + 0.0004\ Xm$	0.49	0.0001
	Davis	$y^{-1} = -0.0068 + 0.0071\ Xm$	0.50	0.0001
		Total DM ($g\ plant^{-1}$)		
1.8	Cobb	$y^{-1} = 0.0029 + 0.0047\ Xm$	0.80	0.0001
	Davis	$y^{-1} = -0.0290 + 0.0411\ Xm$	0.90	0.0001
5.1	Cobb	$y^{-1} = -0.0046 + 0.0151\ Xm$	0.36	0.0001
	Davis	$y^{-1} = -0.0366 + 0.0416\ Xm$	0.66	0.0001
14.3	Cobb	$y^{-1} = 0.0270 + 0.0060\ Xm$	0.49	0.0001
	Davis	$y^{-1} = -0.0971 + 0.101\ Xm$	0.50	0.0001

REFERENCES

Agboola, A. A., and A. A. Fayemi. 1971. Preliminary trials on the intercropping of maize with different tropical legumes in Western Nigeria. J. Agric. Sci. 77:219-225.

Ahmed, S., and M. R. Rao. 1982. Performance of maize-soybean intercrop combinations in the tropics: Results of a multi-location study. Field Crop Res. 5:147-161.

Akanda, M. E., and M. A.Quayyum. 1982. Effect of intercropping soybean, cowpea, mungbean, blackgram and groundnut with maize. Bangladesh J. Agric. Res. 7:66-69.

Allen, J. R., and R. K. Obura. 1983. Yield of corn, cowpea and soybean under different intercropping systems. Agron. J. 75:1005-1009.

Allison, J. C. S. 1969. Effect of plant population on the production and distribution of dry matter in maize. Ann. Appl. Biol. 63:135-144.

Baenziger, P. S., and D. V. Glover. 1980. Effect of reducing plant population on yield and kernel characteristics of sugary-2 and normal maize. Crop Sci. 20:444-447.

Bagnara, D. 1985. Effect of population stress and intra-ear growth relationships on kernel yield in ten corn (Zea mays L.) hybrids. Agric. Can. Res. Sta. Maydica. 30:339-351.

Baker, T. C., and C. A. Francis. 1985. Agronomy of multiple cropping system. pp. 161-182. In C. A. Francis (ed.) Multiple cropping systems. Macmillan Publishing Company, New York.

Bauman, L. F. 1960. Relative yield of first (apical) and second ears of semi-prolific southern corn hybrids. Agron. J. 52:220-228.

Beets, W. C. 1982. Multiple cropping and tropical farming systems. Westview Press, Inc., Boulder, Colorado.

Beste, C. E. 1976. Co-cropping sweetcorn and soybeans. Hort. Sci. 11:236-238.

Bleasdale, J. K. A. 1967a. The relationship between weight of a plant part and total weight as affected by plant density. J. Hort. Sci. 42:51-58.

Bleasdale, J. K. A. 1967b. Systematic designs for spacing experiments. Expl. Agric. 3:73-85.

Brougham, R. W. 1956. Interception of light by the foliage of pure and mixed stands of pasture plants. Aust. J. Agric. Res. 9:39-52.

Buttery, B. R. 1969. Analysis of the growth of soybeans as affected by plant population and fertilizer. Can. J. Plant Sci. 49:675-684.

Carberry, P. S., L. C. Campell, and F. R. Bidinger. 1985. The growth and development of pearl millet as affected by plant population. Field Crops Res. 11:193-205.

Chui, J. A. M., and R. Shibles. 1984. Influence of spatial arrangement of maize on performance of an associated soybean intercrop. Field Crops Res. 8:187-198.

Crookston, R. K., and D. S. Hill. 1979. Grain yields and land equivalent ratios from intercropping corn and soybeans in Minnesota. Agron. J. 71:41-44.

Cunard, A. C. 1976. The influence of interplanting on yield parameters of component plants (high-lysine corn and edible soybeans). In J. Ruttle (ed.) Interplanting. Rodale Press, Inc., Emmaus, Penn.

Dalal, R. C. 1977. Effect of intercropping of maize with soya bean on grain yield. Trop. Agric. 54:189-191.

Daughty, C. S. T., K. P. Gallo, and M. E. Bauer. 1983. Spectral estimates of solar radiation intercepted by corn canopies. Agron. J. 75:527-531.

Davis, J. H. C., and S. Garcia. 1983. Competitive ability and growth habit of indeterminate beans and maize for intercropping. Field Crop Res. 6:59-75.

de Wit, C. T. 1960. On competition. Versl. Landbouwkd. Onderz. 66:1-82.

de Wit, C. T., and J. P. van den Bergh. 1965. Competition between herbage plants. Neth. J. Agric. Sci. 13:212-221.

Donald, C. M. 1963. Competition among crop and pasture plants. Adv. Agron. 15:1-118.

Duncan, W. G. 1958. The relationship between corn population and yield. Agron. J. 50:82-84.

Duncan, W. G. 1972. Plant spacing, density, orientation and light relationships as related to different corn genotypes. Corn Sorghum Res.Conf. Proc. 29:159-167.

Duncan, W. G. 1984. A theory to explain the relationship between corn population and grain yield. Crop Sci. 24:1141-1145.

Duncan, W. G., W. A. Williams, and R. S. Loomis. 1967. Tassels and the productivity of maize. Crop Sci. 7:37-39.

Early, E. B., R. J. Miller, G. L. Reichert, R. H. Hageman, and R. D. Seif. 1966. Effects of shade on maize production under field conditions. Crop Sci. 6:1-6.

Edje, O. T., and D. R. Laing. 1980. Physiological aspects of maize and beans in monoculture and in association. pp. 69-70. In C. L. Keswni and B. J. Ndunguru (eds.) Intercropping, Proceedings of the 2nd Symposium on Intercropping in Semi-Arid Areas, Morogoro, Tanzania, 4-7 August, 1980. Inter. Dev. Res. Centre, Ottowa, Canada.

Egli, D. B., and J. E. Leggett. 1973. Dry matter accumulation patterns in determinate and indeterminate soybeans. Crop Sci. 13:220-222.

Fery, R. L., and J. Janick. 1971. Response of corn (Zea mays L.) to population pressure. Crop Sci. 11:220-224.

Finlay, R.C. 1974. Intercropping soybeans with cereals. In Proceedings of the Regional Soybean Conference, Addis Abeba, Ethiopia, 14-17 October 1974.

Francis, C. A. 1985. Distribution and importance of multiple cropping. pp. 3-19. In C. A. Francis (ed.) Multiple cropping systems. Macmillan Publishing Company, New York.

Francis, C. A., C. A. Flor, and S. R. Temple. 1976. Adapting varieties for intercropped systems in the tropics. pp. 235-253. In R. I. Papendick, P. A. Sanchez, and G. B. Triplett (eds.) Multiple cropping. Amer. Soc. Agron. Spec. Publ. 27, Madison, Wisconsin.

Francis, C. A., M. Praeger, and G. Tejada. 1982. Density interactions in tropical intercropping. II. Maize (Zea mays L.) and bush beans (Phaseolus vulgaris L.). Field Crops Res. 5:253-264.

Galal, S., L. Hindi, M. M. F. Abdalla, and A. A. Metwalley. 1980. Soybean and corn yields under different intercropping patterns. Dept. of Agron. Rept., Cairo Univ., Giza, Egypt.

Gamma, T., and A. Thiruketheeswaran. 1984. Studies on maize (Zea mays L.) and bean (Phaseolus vulgaris L.) intercrop system with particular reference to plant population. Japanese J. Crop Sci. 53:403-408.

Gardner, F. P., R. B. Pearce, and R. L. Mitchell. 1985. Physiology of crop plants. Iowa State University Press, Ames, Iowa.

Grogan, C. O., P. M. Chinwuba, and M. S. Zuber. 1961. Interaction of detasseling sterility and spacing on yields of maize hybrids. Crop Sci. 1:279-282.

Hall, A. J., H. D. Ginzo, J. H. Lemcoff, and A. Soriano. 1981. Influence of drought during pollen-shedding on flowering, growth, and yield of maize. Zeitschrift fuer Acker-und Pflanzenban. 149:287-298.

Hanway, J. J., and C.R. Weber. 1971. Dry matter accumulation in soybean plants as influenced by N, P, and K fertilization. Agron. J. 63:263-266.

Harris, K. E., R. H. Moll, and C. W. Stuber. 1976. Control and inheritance of prolificacy in maize. Crop Sci. 16:843-850.

Hart, R. D. 1975. A bean, corn and manioc polyculture cropping system. I. The effect of interspecific competition on crop yield. Turrialba 25:294-301.

Harwood, R. R. 1979. Small farm development. Westview Press, Boulder, Colorado.

Herbert, S. J., and G. V. Litchfield. 1984. Growth response of short-season soybean to variations in row spacing and density. Field Crops Res. 9:163-171.

Hiebsch, C. K. 1980. Principles of intercropping: Effects of nitrogen fertilization, plant population, and crop duration on equivalency ratios in intercrop versus monoculture comparisons. Ph.D. Dissertation, Raleigh, North Carolina.

Hiebsch, C. K., and R. E. McCollum. 1987. Area-x-time equivalency ratio: A method for evaluating the productivity of intercrops. Agron. J. 79:15-22.

Huxley, P. A., and Z. Maingu. 1978. Use of a systematic spacing design as an aid to the study of intercropping: Some general considerations. Expl. Agric. 14:49-56.

Ibrahim, A. F., K. M. Al-Kawi, and A. A. Salman. 1977. Performance of corn (Zea mays L.) and soybean [Glycine max (L.) Merr.] under intercropping in alternative rows and at different plant population densities. Zeitschrift fur Acker-und Pfanzenbau. 145:224-237.

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1976. Annual Report 1975. Hyderabad, India.

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1977. Annual Report 1976. Hyderabad, India.

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1978. Annual Report 1977. Hyderabad, India.

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1981. Annual Report 1981. Hyderabad, India.

IRRI (International Rice Research Institute). 1973. Cropping system program report. In 1974 Annual Report, Los Banos, Philippines.

IRRI (International Rice Research Institute). 1974. Cropping system program report. In 1975 Annual Report, Los Banos, Philippines.

IRRI (International Rice Research Institute). 1975. Cropping system program report. In 1976 Annual Report, Los Banos, Philippines.

Johnson, G. R. 1973. Relationships between yield and several yield components in a set of maize hybrids. Crop Sci. 13:649-651.

Kamel, M. S., M. S. Abdel-Raouf, E. A. Mahmoud, and R. B. Bayoumi. 1983. Response of corn and soybean to some intercropping systems and chemical herbicides under Egyptian conditions. Annals of Agric. Sci., Moshtohor. 19:27-44.

Karim, M., A. Baksh, and P. Shah. 1983. Effect of plant population, nitrogen application and irrigation on yield components of synthetic-66 maize. J. Agric. Res., Pakistan 21:57-69.

Khudair, H. A., and T. A. Essa. 1985. Response of soybeans to nitrogen fertilizer and plant population. Iraqi J. Agric. Sci. "Zanco" 3-2:21-31.

Kimio Nakaseko, and Kanji Gotoh. 1976. Physio-ecological studies on prolificacy in maize. I. Differences in dry matter accumulation among one-, two-, and three-eared plants. Proc. Crop Sci. Soc. Japan 45:263-269.

Krishnamurthy, K., A. Bommegowda, M. K. Jagannath, N. Venugopal, T. V. R. Prasad, G. Kaghunatha, and B. G. Rajashekara. 1975. Relative production of yield in hybrid, composite, and local maize as influenced by nitrogen and population levels. I. Grain yield and its components. Indian J. Agron. 19:263-266.

Lamera, E. C., and H. M. Pava. 1983. Yield and agronomic traits of Clark-63 soybean cultivar as affected by plant population density and phosphorus fertilization. CMU J. Agric. Food Nutr. 5:617-631.

Lang, A. L., J. W. Pendleton, and G. H. Dungan. 1956. Influence of population and nitrogen levels on yield and protein and oil contents of nine corn hybrids. Agron. J. 48:284-289.

Leopold, A. C., and P. E. Kriedemann. 1975. Plant growth and development. 2nd ed. McGraw-Hill, New York.

Loomis, R. S., W. A. Williams, W. G. Duncan, A. Dovrat, and F. Nunez. 1968. Quantitative descriptions of foliage display and light absorption in field communities of corn plants. Crop Sci. 8:352-356.

Maia, A. C., A. M. de Rezende, and J. P. del C. Laca-Buendia. 1982. Effect of spacing and plant population on weed control in soyabean on cerrado soils. Centro Nacional de Pesquisa de Soja Report, Londrina, Brazil.

McGilchrist, C. A. 1965. Analysis of competition experiments. Biometrics 25:397-402.

Mead, R., and R. W. Willey. 1980. The concept of a land equivalent ratio and advantages in yields from intercropping. Expl. Agric. 16:217-228.

Mongi, H. O., M. S. Chowdhury, and C. S. Nyeupe. 1980. Influence of intercropping methods on foliar NPK contents and yields of maize and cowpea. pp. 67-68. In C. L. Keswni and B. J. Ndunguru (eds.) Intercropping, Proceedings of the 2nd Symposium on Intercropping in Semi-Arid Areas, Morogoro, Tanzania, 4-7 August, 1980. Inter. Dev. Res. Centre, Ottowa, Canada.

Nelder, J. A. 1962. New kinds of synthetic designs for spacing experiments. Biometrics 18:283-307.

Nnko, E.M., and A. L. Doto. 1980. Intercropping maize or millet with soybean, with particular reference to planting schedule. pp. 33-36. In C. L. Keswni and B. J. Ndunguru (eds.) Intercropping, Proceedings of the 2nd Symposium on Intercropping in Semi-Arid Areas, Morogoro, Tanzania, 4-7 August, 1980. Inter. Dev. Res. Centre, Ottowa, Canada.

Norman, D. W. 1974. Rationalizing mixed cropping under indigenous conditions: The example of Northern Nigeria. J. Develop. Studies 11:3-21.

Okigbo, B. M. 1979. Evaluation of plant interactions and productivity in complex mixtures as a basis for improved cropping systems design. pp. 155-179. In Proceedings of the International Workshop on Intercropping, 10-13 January 1979, Hyderabad, India.

Osiru, D. S. O., and R. W. Willey. 1972. Studies on mixtures of dwarf sorghum and beans (Phaseolus vulgaris) with particular reference to plant population. J. Agric. Sci. Camb. 79:531-540.

Parvez, A. Q., F. P. Gardner, and K. J. Boote. In press. Vegetative and reproductive growth of determinate and indeterminate soybean influenced by planting pattern, density and date. Crop Sci.

Pearce, R. B., R. H. Brown, and R. E. Blaser. 1965. Relationship between leaf area index, light interception and net photosynthesis in orchardgrass. Crop Sci. 5:553-556.

Poneleit, C. G., and D. B. Egli, 1979. Kernel growth rate and duration in maize as affected by plant density and genotype. Crop Sci. 19:385-388.

Prior, C. L., and W. A. Russell. 1975. Yield performance of nonprolific and prolific maize hybrids as six plant densities. Crop Sci. 15:482-486.

Putman, D. H., and S. J. Herbert. 1981. Planting patterns of intercropped corn and soybeans for silage. Agron. Abstr., 73rd Annual Meeting, American Society of Agronomy.

Rose, S. J., O. C. Burnside, J. E. Specht, and B. A. Swisher. 1984. Competition and allelopathy between soybeans and weeds. Agron. J. 76:523-528.

Rutger, J. N. 1971. Effect of plant density on yield of inbred lines and single crosses of maize (Zea mays L.). Crop Sci. 11:475-476.

Ruthenberg, H. 1976. Farming systems in the tropics. 2nd ed. Clarendon Press, Oxford.

Serpa, J. E. S., L. A. N. Fontes, J. D. Galvao, and A. R. Conde. 1981. Comportamento do milho e do feijao em cultivos exclusivos consorciados e em faixas alternadas. Revista Cere. 228:236-252.

Shibles, R. M., and C. R. Weber. 1965. Leaf area, solar radiation interception and dry matter production of soybeans. Crop Sci. 5:575-577.

Shibles, R. M., and C. R. Weber. 1966. Interception of solar radiation and dry matter production by various soybean planting patterns. Crop Sci. 6:55-59.

Shinozaki, K., and T. Kira. 1956. Intraspecific competition among higher plants. VII. Logistic theory of the C-D effect. J. Inst. Poly. Osaka City Univ. D7:35-72.

Singh, N. D. 1977. Effect of intercropping maize with soybean on nematode population and grain yield. Fac. Agric. West Indies Univ., St. Augustine, Trinidad.

Stinson, H. T., Jr., and D. N. Moss. 1960. Some effect of shade upon corn hybrids tolerant and intolerant of dense planting. Agron. J. 52:482-484.

Stringfield, G. H., and L. E.Thatcher. 1947. Stands and methods of planting corn hybrids. Agron. J. 39:995-1010.

Syarifuddin, A., S. Effendy, I. G. Ismail, and J. L. McIntosh. 1974. Performance of corn, peanut, mungbean and soybean in monoculture and intercrop combination of corn and legumes in dry season 1973. Central Research Institute for Agriculture, Bogor, Indonesia.

Szeicz, G. 1974. Solar radiation for plant growth. J. Appl. Ecol. 11:617-634.

Tetio-Kagho, F. 1979. Evaluation of shade tolerance of seven cowpea [Vigna unguiculata (L.) Walp] cultivars. M.Sc. Thesis, University of Ibadan, Nigeria.

Tetio-Kagho, F. 1980. Relative competitive abilities of some cowpea cultivars intercropped with maize. M. Phil. Dissertation, University of Ibadan, Nigeria.

Thompson, D. R. 1977. Effect of cereal height on performance of stands intercropped with soybean. M.Sc. Thesis, University of Dar es Salaam, Morogoro, Tanzania.

Trenbath, B. R. 1974. Biomass productivity of mixtures. Adv. Agron. 26:177-210.

Trenbath, B. R. 1976. Plant interactions in mixed crop communities. pp. 129-169. In R. I. Papendick, P. A. Sanchez, and G. B. Triplett (eds.) Multiple cropping. Amer. Soc. Agron. Spec. Publ. 27, Madison, Wisconsin.

Tsai, C. L., and H. W. Chung. 1984. Effects of population density and N-fertilizer on the yield and ear quality of super sweet corn. Research bulletin, Tainan District Agric. Improvement Sta. 18:39-45.

Wahua, T. A. T. 1978. Leaf water potentials and light transmission of intercropped sorghum and soybeans. Expl. Agric. 14:373-380.

Wahua, T. A. T., and D. A. Miller. 1978. Relative yield totals and yield components of intercropped sorghum and soybeans. Agron. J. 70:287-291.

Weber, C. R., R. M. Shibles, and D. E. Byth. 1966. Effect of plant population and row spacing on soybean development and production. Agron. J. 58:99-102.

Willey, R. W. 1979a. Intercropping--Its importance and research needs. Part 1. Competition and yield advantages. Field Crop Abstr. 32:1-20.

Willey, R. W. 1979b. Intercropping--Its importance and research needs. Part 2. Agronomy and research approaches. Field Crop Abstr. 32:73-85.

Willey, R. W., and S. B. Heath. 1970. The quantitative relationships between plant population and crop yield. Adv. Agron. 21:281-321.

Willey, R. W., and D. S. O. Osiru. 1972. Studies on mixtures of maize and beans (Phaseolus vulgaris) with particular reference to plant population. J. Agric. Sci., Camb. 79:517-529.

Williams, W. A., R. S. Loomis, W. G. Duncan, A. Dovrat, and F. Nunez. 1968. Canopy architecture at various population densities and the growth and grain yield of corn. Crop Sci. 8:303-308.

Williams, W. A., R. S. Loomis, and C. R. Lepley. 1965. Vegetative growth of corn as affected by population density. II. Components of growth, net assimilation rate and leaf-area index. Crop Sci. 5:215-219.

Wright, D. L., F. M. Shokes, and R. K. Sprenkel. 1984. Planting method and plant population influence on soybeans. Agron. J. 76:921-924.

BIOGRAPHICAL SKETCH

Tetio Kagho Fidele was born in Bafou, Dschang, Cameroon, in 1952. He attended primary school and secondary school in Bafou (St. Laurent of Bafou), where he obtained a biological sciences diploma in 1971. He entered the University of Yaounde in 1972, obtained a Biological Sciences degree with specialization in agronomy in 1975 (DESGA), and was immediately admitted to the National Advanced School of Agriculture (ENSA) where he graduated in 1977 with the Engineer of Agriculture diploma (with high honors).

Tetio Kagho joined the ENSA faculty of the University Centre of Dschang (UCD) in 1977 as assistant lecturer in the Department of Agriculture. In 1978, he was admitted to the University of Ibadan, Nigeria, where he obtained a Master of Science degree in 1979 and a Master of Philosophy degree in 1981 in crop production (intercropping).

He then returned to Cameroon and taught at ENSA (UCD) from 1981 to 1984. In fall 1984, he enrolled in the University of Florida at Gainesville for his Ph.D. degree in crop production (intercropping).

Tetio is a member of the American Society of Agronomy, Crop Science Society of America, as well as Gamma Sigma Delta Honor Society, and the International Foundation for Science.

He likes sports, especially basketball and soccer. He is married and has one wife, a daughter and two sons.

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Franklin P. Gardner, Chairman
Professor of Agronomy

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Kenneth J. Boote
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